Tree Risk Assessment

MANUAL

Third Edition

International Society of Arboriculture

Tree Risk Assessment

Manual

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International Society of Arboriculture

Tree Risk Assessment Manual

Third Edition

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Contents

Preface iv
Use of Shall, Should, and Must v
Disclaimer vi
Acknowledgments vi

Module 1. Introduction to Tree Risk Assessment 1
Case Study: Is a Tree Risk Assessment Needed? 9
Case Study: Scope of Work 14

Module 2. Levels of Assessment 21
Case Study: Holding Factors Constant in a Level 1 Assessment 28

Module 3. Target Assessment and Tree Risk Factors 43
Case Study: Occupancy Rate and Likelihood of Impact 58

Module 4. Site Assessment 71
Case Study: The Influence of Site Factors 86

Module 5. Tree Biology and Mechanics 89
Case Study: Interpreting Observations 97
Case Study: Sounding and Probing to Assess Decay 113
Case Study: The Need for Advanced Assessment 124
Case Study: Assessing the Extent of Internal Decay 128

Module 6. Tree Inspection and Assessment 131
Case Study: Assessment of a Shear Plane Crack 145
Case Study: Tree Lean and Likelihood of Failure 150

Module 7. Data Analysis and Risk Categorization 159
Case Study: Using the Matrices 170

Module 8. Mitigation 173
Case Study: Providing Mitigation Options 185

Module 9. Reporting 189
Case Study: Reporting 196

Appendix. Using the ISA Basic Tree Risk Assessment Form 201
Glossary of Terms 218
Selected References and Other Sources of Information 228
Index 230

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Preface

Trees are a significant component of life in urban and rural areas, providing many benefits to people, communities, and the environment. Some of these benefits have quantifiable value, such as improved stormwater management, enhanced air quality, reduced summer air temperatures, and increased property values. Other benefits—such as aesthetics, sense of place, or spiritual significance—are less quantifiable but nonetheless important to people and their well-being.

Trees are biological organisms that grow, age, and eventually die. They are structures composed of roots, trunk, branches, and leaves that are exposed to wind, rain, snow and ice loads. When the loads exceed the load-bearing capacity of the tree's supporting wood, tree parts may break and fall. When trees fall, people, property, and activities may be injured, damaged, or disrupted. Assessing the likelihood of that occurring as well as estimating the amount of damage that would happen as a result are the subjects of this course.

All urban trees have the potential to become an unacceptable risk at some point, but that does not mean we should prematurely condemn them. Tree managers (owners or people acting on their behalf) have a duty of care to ensure that the trees in their care do not create an unreasonable risk to people and property. Tree managers, and society in general, must take a balanced and proportionate approach to managing risk. Eliminating all risk would eliminate all trees and the wide array of benefits they provide.

The goal of tree risk management is to provide a systematic and defensible approach by which risks can be assessed and managed to a reasonable level. An understanding of tree risk provides a robust foundation for achieving that goal. A risk assessor's assessments and recommendations should be systematic and structured based on science and arboriculture. Risk assessors should also familiarize themselves with all applicable local, regional, and national safety regulations that may affect risk management and tree worker safety.

Since its initial release in 2011, the qualitative methodology first outlined in the International Society of Arboriculture's (ISA's) Best Management Practices (BMP)—*Tree Risk Assessment* has been widely adopted and is proving to be an effective approach to risk assessment within arboriculture, urban forestry, and vegetation management. Despite this success, ISA has made important updates and improvements to this version of the *Tree Risk Assessment Manual* while ensuring that it aligns with the revised BMP publication.

The following is a summary of new or revised material and guidance in this manual:

- The text and terminology have been updated to be consistent with ISA's BMP—*Tree Risk Assessment*, Third Edition (2025).
- Terms have been defined to be consistent with other disciplines. For example, the weather section (Module 4) was broadened and includes three categories: *normal*, *severe*, and *extreme*, as defined by meteorologists. To be consistent with engineering terminology, *failure mode* was changed to *failure type* to refer to the manner in which a tree or tree part could fail or has failed.
- Key terms have been defined at the beginning of each section.
- Modules 1, 3, 4, and 5.3 were reorganized to improve flow and comprehension.
- The type of work to be performed in a tree risk assessment, a tree inspection, and a worksite inspection has been described.
- New guidance for assessing the likelihood of impact has been provided.

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- Advanced assessment techniques descriptions have been expanded. Use of advanced techniques (e.g., drilling, tomography) to quantify the extent of decay, how decay reduces load bearing, and limitations of formulas to estimate loss of load-bearing capacity have been expanded.
- Several case studies have been rewritten or added, including an example of a written tree risk assessment report.
- More drawings, photos, and diagrams have been added to illustrate key concepts.
- In each module, key information has been summarized in sidebars.
- The roles of the tree risk manager and the tree risk assessor have been clarified.
- Additional guidance for calibrating assessments and ratings has been added.
- Consideration for wildlife habitat has been expanded throughout the text.
- The ISA "Basic Tree Risk Assessment Form" has been revised to enhance ease of use and to reflect changes in terminology.

Tree risk assessment is used to determine the risk of failure a tree poses to people, property, or activities. Tree risk managers can be proactive by identifying high-risk situations before accidents occur and taking action so that damage to property or people can be avoided. The tree risk manager will know if the structural integrity of the tree is acceptable (or can be made acceptable if some mitigation work is undertaken) within their threshold for acceptable risk. The benefits conferred by the tree are then retained without undue risk.

Risk assessment should not be used as an excuse to remove trees that are healthy and low risk. A tree owner may want a tree removed because it blocks a vista or drops debris, but the tree might be protected by local ordinance. Aesthetics and client desires should not bias your professional judgment.

The *Tree Risk Assessment Manual* is designed to provide tree risk assessors with the basic knowledge and methodology needed to perform a competent assessment. The information and methods covered are complex and have been synthesized from a wide array of technical literature. This systematic and structured approach to assessing tree risk is intended to help risk managers strike a balance between the risk a tree poses and the benefits that trees provide to individuals and communities. As knowledge of tree biology and risk management grows, the methodology will continue to serve the industry while evolving and adjusting to new research and ways of thinking about risk assessment.

Use of Shall, Should, and Must

Standards and regulations such as ANSI, OSHA, ISO, and others regionally and internationally may have specific requirements for the use of "shall," "should," and "must." For the sake of readability and to account for differences among standards, this publication does not necessarily parallel the requirements of such standards or regulations in the use of these terms.

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Disclaimer

Practitioners of tree risk assessment do so at their own risk. Neither the International Society of Arboriculture nor the authors accept any responsibility, explicit or implied, for liability, loss, or consequential damage arising from the manner in which the materials presented in this manual are used in the field. The training materials provided are considered to be reasonable and sufficient to provide users with a basic understanding of when and how to undertake tree risk assessments.

The contents of this manual are provided "as is" and "where is" and may change without notice as research and understanding of tree biology, tree mechanics, and risk assessment evolve.

Acknowledgments

Writing a manual of this complexity requires considerable input and review to ensure that the technical aspects are correct and that the writing is clear and concise. While there are, inevitably, differences of opinion about how some aspects are interpreted—and, in some cases, whether or not they should be included—we have made every effort to present the most current information available. Even so, we are very aware that as new research results and concepts emerge, there will be changes in the way that tree risk assessment is considered and practiced. Future editions of this text will incorporate these changes as they are adopted.

Many people have made significant contributions to the ISA Tree Risk Assessment program:

The original ISA panel of experts:

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Much of the text included in this Third Edition was taken directly from ISA BMP—*Tree Risk Assessment*, Third Edition (2025). More than 100 experts from around the world were invited to review that document. Over 1,200 comments were received from 35 professionals representing seven countries.

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Introduction to Tree Risk Assessment

Module I

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Introduction to Tree Risk Assessment

Module 1

Learning Objectives

- Explain the purpose of tree risk assessment and how the process considers the benefits of trees and potential risks.
- Discuss the factors to consider in deciding what constitutes reasonable and proportionate risk assessment and management.
- Describe how tree risk assessment fits into the larger context of tree risk management.
- Explain how the roles of the risk manager and the risk assessor differ.
- Define the basic terms used in tree risk assessment.
- Explain the key differences between a tree risk assessment and a tree inspection.
- Discuss the elements that should be included in the scope of work, including why it should be defined and agreed upon in advance.
- Describe the steps involved in the risk assessment process.

Key Terms

arborist
breach of duty
consequences
context
duty of care
ethics
harm
hazard
legal precedents
likelihood of failure
likelihood of impact
limitations
negligence
qualitative risk assessment
quantitative risk assessment
risk rating
scope of work
standard of care
target
time frame
tree conflict
tree failure
tree inspection
tree risk assessment
tree risk assessor
tree risk evaluation
tree risk management
tree risk manager
worksite inspection

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Introduction

The benefits that trees provide to people living and working in the urban environment range from ecological and monetary to aesthetic and sociological. These benefits increase as the age and size of the trees increase. However, as a tree gets older and larger, it is also more likely to shed branches or develop decay or other conditions that can predispose it to failure. In addition, large trees have greater mass than smaller trees, and the consequences of large tree failure can be more serious.

In assessing and managing trees, the tree risk manager needs to balance the risk that a tree poses against the personal, societal, and ecological benefits that it provides.

Some level of risk exists wherever trees coexist with people or property. In most cases, the risk is low. The National Tree Safety Group (NTSG), a partnership of organizations in the United Kingdom, has drafted a guidance document (National Tree Safety Group 2024) that identifies five key principles for tree risk management. The guidance document provides a foundation for balancing tree risk and the benefits that trees provide:

- Trees provide a wide variety of benefits to society.
- Trees are living organisms that naturally lose branches or fall.
- The risk to human safety is extremely low.
- Tree owners have a legal duty of care.
- Tree owners should take a balanced and proportionate approach to tree safety management.

Definitions of Some Key Terms

Tree risk assessment uses specific terms that are important to understand. Below is a partial list of these terms. A more comprehensive list can be found in the Glossary of Terms.

risk rating—the categorization of risk based on the combination of the likelihood of tree failure and impact with the potential consequences.

time frame—the period for which an assessment is defined.

tree risk assessment—a systematic process used to identify, analyze, and communicate tree risk.

tree risk assessor—an arborist with specialized education, training, skills, experience, and competency to conduct tree risk assessments.

tree risk evaluation—the process of comparing the assessed risk with risk criteria to determine if the risk is acceptable.

tree risk management—the application of policies, procedures, and practices to identify, analyze, communicate, evaluate, mitigate, and reassess.

tree risk manager—the person responsible for tree management or the controlling authority that regulates tree management. Examples include clients, property owners, municipalities, and utilities.

Types of Risk Associated with Trees

Trees can pose a variety of risks, which are categorized into two groups: conflicts and failures.

Conflicts

Risk can arise when there are conflicts between trees and societal functions. As trees grow, they produce flowers, fruits, roots, branches, and leaves, and any of these may interfere with people, property, or activities. In some situations, these conflicts can cause harm. For instance, a sidewalk lifted by tree roots creates a tripping hazard (Figure 1.1). Conflict can also occur when trees are in contact with electric power lines, as this contact can interrupt power supply, ignite fires, and/or injure or kill people.

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Luana Vargas

Nelda Matheny

Figure 1.1 Raised sidewalks can result in pedestrians tripping, causing injury. In addition, flowers, fruit, and seeds from trees can cause slipping hazards and nuisances for pedestrians. These and other tree-related conflicts are important but are not covered extensively in this publication.

E. Thomas Smiley

Figure 1.2 In assessing and managing trees, the tree risk manager needs to balance the risk that a tree poses against the personal, societal, and ecological benefits that it provides.

Structural Failures

Tree failure is the breakage of stems, branches, or roots or the loss of mechanical support in the soil-root system. Unless specifically stated otherwise, in this manual, "tree failure" means failure of the whole tree, branch, or other parts. Failures occur when the load(s) exceed the load-bearing capacity. This typically occurs when defects or conditions in the tree reduce load-bearing capacity, but it can also occur when excessive loads cause failure of a tree without any defects.

Most tree failures involve a combination of a loading event, such as a strong wind, and a structural defect(s) or other condition(s).

This manual focuses on failures of trees growing near people, property, and/or activities.

Figure 1.3 Tree risk management is the application of policies, procedures, and practices to identify, analyze, communicate, evaluate, mitigate, and reassess tree risk. The tree risk assessor is responsible for the tree risk assessment and communicates the findings to the tree risk manager who then evaluates the risk and determines the mitigation to be applied.

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Tree Risk Assessment within the Context of Tree Risk Management

Tree risk management is the application of policies, procedures, and practices to identify, analyze, communicate, evaluate, mitigate, and reassess tree risk (Figure 1.3). Tree risk assessment is the systematic process used to identify, analyze, and communicate tree risk; it is a subset of tree risk management. Various people share responsibilities for tree risk management, including the tree owner or **tree risk manager**, the **tree risk assessor**,

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E. Thomas Smiley

Figure 1.4 Decisions on whether tree assessments are required, or what level of assessment is appropriate, should consider what is reasonable and proportionate to the specific conditions and situations. Because the unpaved, single-lane road (left) has significantly less use than the urban park trees (right), the need for risk assessment is lower.

Tree Risk Manager (client, tree owner, property manager, controlling authority)	Tree Risk Assessor (qualified arborist engaged by tree risk manager specifically to conduct TRA)	Arborist (municipal, utility, commercial sales, consulting, or production arborist performing tree work)

• Define and communicate tree risk management policies
• Determine the need to inspect or assess the trees in question
• Identify the geographical limits of the tree risk assessment
• Specify the desired level of tree risk assessment
• Develop scope of work, including time frame (advice from tree risk assessor)
• Establish the budget
• Provide to the assessor relevant background, site use, target, and occupancy rate information
• Decide the level of acceptable risk
• Evaluate tree risk and compare to risk threshold
• Choose among risk mitigation options
• Prioritize and schedule work
• Establish the reassessment interval
	• Accept scope of work, including time frame
	• Identify tree and site conditions to inspect
	• Identify specific targets, estimate target zone and occupancy rates
	• Assess and classify the likelihood of tree failure
	• Assess and classify the likelihood of a tree failure impacting a target
	• Assess the potential consequences of a tree failure impacting a target
	• Analyze tree risk
	• Recommend advanced assessments, if appropriate
	• Provide options for mitigation, if appropriate and requested
	• Provide residual risk for any recommended mitigation, if appropriate
	• Recommend time to reassess, if appropriate
	• Provide report to achieve objectives in the scope of work
		• Develop or accept a scope of work with the tree owner or manager
		• Inspect tree and worksite prior to and during the work operation
		• Identify conditions outside the scope of work that may affect the scope of work
		• Provide services:
		  • Pruning
		  • Removal
		  • Support systems
		  • Lightning protection
		  • Tree health treatments
		  • Transplanting
		  • Tree replacement

Figure 1.5 Roles of the tree risk manager, tree risk assessor, and the arborist. In some cases, a person may have more than one role. Legal counsel can provide advice on duty of care, professional responsibilities, negligence, title and boundary matters, avoiding and defending against litigation, and other issues. Recommendations should be made in accordance with industry standards and local regulations.

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Reasonable and Proportionate

Tree risk managers are advised to consider what is reasonable and proportionate to the specific conditions and situations before deciding whether a tree risk assessment is required or what level of assessment is appropriate. But what does that mean?

Reasonable means using good judgment that is fair, practical, and sensible.

Proportionate describes something that has a relative size or amount to something else.

Being *reasonable* involves taking actions *proportionate* to the risk.

In tree risk assessment, reasonable and proportionate means that the time and resources put into the assessment and mitigation are in balance with the likelihood of the target being impacted and the harm that may be done. For a tree in good condition that rarely has a target near it, it would not be reasonable or proportionate to perform tree risk assessments on a frequent basis. For instance, performing annual risk assessments and advanced trunk decay tests on a tree along an unpaved, infrequently used road is disproportionate to its use and likelihood for injury. Where use or potential consequences are very low, the tree risk manager may determine that conducting a tree risk assessment is not warranted. On the other hand, for a large, old tree in a frequently used area, conducting annual tree risk assessments may be reasonable and proportionate. Taking actions that are disproportionate to the risk involved can result in unnecessary removal of trees and eliminate the benefits the tree provides.

Decisions must also be made within the framework of applicable laws, standards, and regulations.

and the **arborist** providing tree work (Figure 1.5). Each person has a role in assessing, managing, and/or mitigating tree risk.

Many trees are located where the potential consequences of failure and impact are *minor* or *negligible*. But in urban and developed areas where people could be injured, property damaged, and activities disrupted, the consequences of **tree conflict** (i.e., interference with people, property, or activities) or failure may be *significant* or even *severe*.

It is impossible to maintain trees completely free of risk. Some level of risk must be accepted to experience the benefits that trees provide. Fortunately, tree failure that results in serious damage, injury, or death is rare.

Tree failures during normal weather conditions (Module 4) are sometimes predictable and preventable. However, any tree, whether it has visible weaknesses or not, will fail if the loads applied exceed the load-bearing capacity of the tree or its parts. For example, weather such as strong winds or heavy ice loads can lead to failure of structurally sound trees free of visible defects.

Before deciding whether a tree risk assessment is required or what level of assessment is appropriate, the tree risk manager should consider what is reasonable and proportionate to the specific conditions and situations. These are tree risk management policy issues that should be determined before undertaking a risk assessment.

Tree risk assessments are usually undertaken because the tree risk manager recognizes that the trees have potential to cause damage and/or injury, and they want to manage the risk. This recognition often occurs after one or more trees have failed. Assessments are primarily conducted to assist risk managers anticipate problems and to take appropriate action when risk levels are unacceptable.

Tree risk assessors perform risk assessments with limited information regarding structural condition, immediate environment, site usage, and targets and their occupancy rates. Tree risk assessors form

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opinions about what is likely to occur in the future based on their knowledge, experience, and observations. Uncertainty is inherent in these opinions. Assessments are then provided to a tree risk manager who, based on their risk tolerance and budget, makes tree management decisions.

Tree Risk Assessment, Tree Inspection, and Worksite Inspection

Depending on the scope of work, professionals may perform different tasks: tree risk assessment, tree inspection, or worksite inspection. Professionals may also be responsible for more than one task.

Tree risk assessment is a systematic process to identify, analyze, and communicate tree risk. It is a service that a tree risk assessor provides, when authorized by the tree risk manager. Tree risk assessment uses established criteria such as those described in this publication.

The purpose of a tree risk assessment is to provide information to a tree risk manager to assist with management decisions for the tree or the property. The information typically includes an opinion on the level of risk, recommendations for advanced tree risk assessment (if needed), mitigation options with residual risk ratings if mitigation options are followed, and recommendations for reassessment of the tree or property in the future.

Tree inspection is a visual observation of tree health, structure, and/or form to provide information to the tree owner or manager to guide tree care or management decisions. A tree inspection may be conducted by an arborist during tree inventories, tree health assessments, or vegetation management activities to determine the need for pruning, removal, structural support, lightning protection, soil remediation, pest management, or other management needs. Tree inspections may be comprehensive or directed at a single issue identified by the arborist, tree owner, or tree manager. There is no industry-standardized process for tree inspection.

The purpose of a tree inspection is to gather information for tree care or management decisions. An arborist does not need to be a tree risk assessor to conduct a tree inspection, nor is it necessary that the results of a tree inspection be provided in a written report. Tree inspection is not the same as tree risk assessment, nor are the same criteria necessarily used to determine conditions of concern.

Worksite inspection is a visual observation of a tree and work area. It is conducted by a tree worker prior to and during work operations. If serious defects or conditions of concern are identified, a different work plan may be implemented, or work may be stopped.

The purpose of a worksite inspection is to identify and communicate site and/or tree conditions that may affect the scope of work, work procedures, and/or tree worker safety. Observations are communicated to the supervisor and other workers on the site. Worksite inspection is not the same as tree risk assessment, nor are the same criteria necessarily used to determine conditions of concern.

Risk vs. Hazard

In the past, arborists and foresters used the term *hazard tree assessment* to describe the process of inspecting and evaluating the structural condition of a tree and the harm that could occur if it failed. The more accurate and appropriate term *tree risk assessment* is now standard.

Risk is the combination of the likelihood of an event and the severity of the potential consequences.

A **hazard** is a likely source of **harm**. In relation to trees, a hazard is the tree part(s) that might fail and which is identified as a likely source of harm.

A tree is considered hazardous when it has been assessed and found to be likely to fail and cause an unacceptable degree of injury, damage, or disruption—that is, it poses a *high* or *extreme* risk.

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Table 1.1 Comparison of tree risk assessment, tree inspection, and worksite inspection

	Tree Risk Assessment	Tree Inspection	Worksite Inspection
Purpose:	Provide information to assist with management decisions for the tree or the property	Gather information for tree care or management decisions	Identify and communicate site and/or tree conditions that may affect the scope of work, work procedures, and/or tree worker safety
Provides information to:	Tree risk manager	Tree owner or manager	Supervisor and other workers
Contract and/or scope of work agreed to prior to assessment or inspection?	Yes	Optional	Yes
Tree location identified?	Yes	Yes	Yes
Tree visually inspected?	Yes	Yes	Yes
Likelihood of failure, likelihood of impact, and consequence categorized?	Yes, when using the ISA *Tree Risk Assessment* BMP methodology	No	No
Tree risk rating(s) developed?	Yes, based on scope of work	No	No
Risk mitigation recommended?	Yes, based on scope of work	Optional	Optional
Tree risk report presented or submitted?	Yes	No	No
Recommendation for reassessing the tree?	Optional	Optional, unless required by standards or jurisdiction	No

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CASE STUDY

Is a Tree Risk Assessment Needed?

A passing motorist noticed this dead tree along a busy residential street and called the city to report it. The motorist suggested a tree risk assessment. The city arborist, who is also the tree risk manager for the city, inspected the tree and determined that a tree risk assessment was not needed. The tree was a likely source of harm and should be removed as soon as possible.

Because the tree was growing between the electrical power and communications wires, the removal was coordinated with the local electric power utility company. The tree and stump were removed within a week and a small-maturing tree will be planted in this location.

While tree risk assessments using the methodology presented in this publication can be conducted on dead trees, especially those that may in part be retained for wildlife habitat, in many cases the problem and solutions are clear, so no further assessment is needed.

Photo by E. Thomas Smiley

Approaches to Risk Assessment

Tree risk assessment is the systematic process used to identify, analyze, and communicate tree risk. The way this process is applied depends on the context and the methods used to carry out the risk assessment. Before a tree risk assessment takes place, it is important to establish the context of the risk assessment. **Context** defines the parameters of the risk assessment including objectives, how risk will be evaluated, communication flow, applicable policies or legal requirements, and **limitations** of the risk assessment.

The two approaches to risk assessment are *quantitative* and *qualitative*. Each has advantages and limitations, and each may be appropriate with different objectives, requirements, resources, and uncertainties. Quantitative risk assessments have been applied to populations of trees. However, all current tree risk assessment methodologies used for individual trees are qualitative, even though some methodologies include numeric categories or components.

Quantitative Risk Assessment

Quantitative risk assessment determines numeric values for the probability and consequences of events and then calculates a risk value, typically based on the following formula:

Risk = Probability × Consequences

An advantage of quantitative assessment is that tree risk can be compared not only to other tree populations but also to other types of risk. This might be necessary for municipal decisions in which resources must be allocated among departments.

Quantitative assessments can be used for large populations of trees based on statistical probabilities and calculated consequences. Such assessments are not applied to individual trees in the population

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because of the lack of data and the uncertainty associated with estimating the various risk factors.

Qualitative Risk Assessment

Qualitative risk assessment is the process of using categorized ratings of the likelihood and consequences of an event to classify risk. Ratings are often combined in a matrix to categorize risk.

Inherent subjectivity and ambiguity are limitations of the qualitative approach. To increase reliability and consistency of application, it is important to provide clear explanations of the terminology and significance of the ratings defined for likelihood, consequences, and risk. Qualitative risk assessment approaches can use simple terminology, and they are accepted methods of risk assessment that are used internationally by many governments and businesses.

Qualitative Numeric Assessments

Several numeric tree risk assessment systems have been developed that assign numbers to certain factors to derive an estimate or ranking of relative risk. These systems employ categorizations and are qualitative assessments. The assigned number ratings do not represent a mathematical relationship. Risk professionals caution that addition or multiplication of these ordinal numbers is mathematically incorrect.

TRAQ Tree Risk Assessment Approach

The approach used in TRAQ is a qualitative risk assessment to provide information about the level of risk posed by a tree over a specified time frame. This is accomplished by categorizing the likelihood and consequences of an event. These factors are determined by categorizing the following:

a) the likelihood of failure of a tree within the specified time frame,

b) the likelihood that a failed tree could impact a person(s) or property or disrupt activities within the specified time frame, and

c) the consequences of the failed tree impacting the **target**.

Using ratings for the **likelihood of failure**, **likelihood of impact**, and severity of **consequences**, the assessor categorizes the tree's risk rating. **Risk rating** is the term describing the level of risk based on the assessor's rating of the likelihood and consequences of an event. The ratings are words, not numbers.

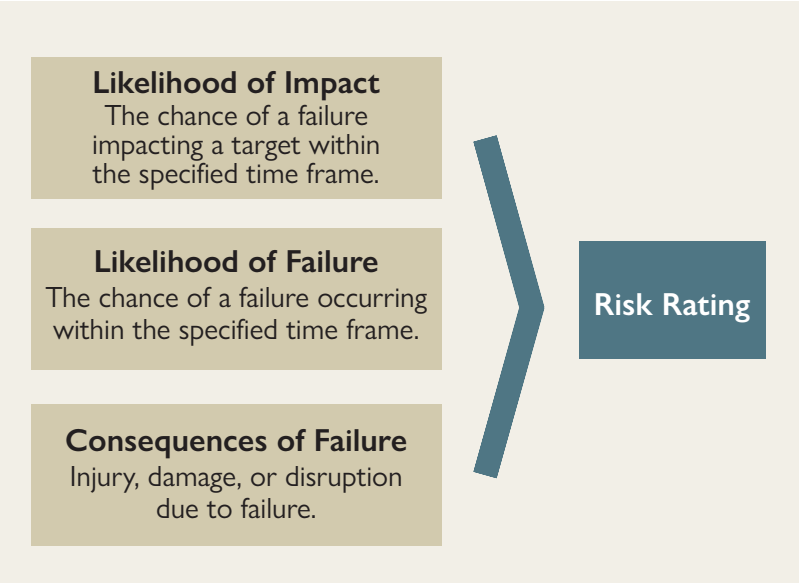

Figure 1.6 After assessing the target, tree, and site, the tree risk assessor combines ratings for likelihood of impact, likelihood of failure, and consequences of failure to arrive at a risk rating for the tree.

For a single tree, the risk rating for various tree parts can be very different. It is important to define what risk is being rated. For example, "the risk of the large, dead branch in the oak tree in the homeowner's backyard failing and striking the garage within a year" may be very different from "the risk of the oak tree in the homeowner's backyard failing at the base and striking a person underneath the tree within a year." Therefore, the assessment report should state clearly what risk(s) are rated to minimize confusion.

Defining the Scope of Work

The **scope of work** should be defined prior to beginning a tree risk

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assessment. The tree risk assessor and tree risk manager must agree on the goals, limitations, and budget of the tree risk assessment. Some tree risk managers may be experienced and have prepared a scope of work. Often, however, the tree risk assessor plays a significant role in developing the scope of work.

When developing the scope of work, local authority or permitting agency requirements for assessments and reporting should be considered.

The scope of work should include the following:

E. Thomas Smiley

Figure 1.7 Although much attention is focused on whole-tree failures, the majority of failures are branches.

1. **The tree(s) or area to be assessed.** Assessment area identification may be based on the location of a tree (e.g., "the large oak tree in the front yard") or it may include selection criteria (e.g., "all trees on Main Street with a stem diameter greater than 12 in [30 cm]").

   Property boundaries that affect access to the tree(s) or affect which trees should be assessed need to be identified. It is the tree risk manager's duty to identify boundaries, but when in doubt, the assessor has a duty to inquire about their location.

2. **The level and details of the assessment.** One or more of the three levels of assessment (1, 2, 3, as defined later) should be specified, as well as details discussed in the next section that are to be included within each level. If a Level 1, limited visual assessment is selected, how the assessment will be conducted, the perspective, and what information will be recorded are specified—for example, "The assessment procedure is a 'walk-by' from the sidewalk, looking for any obvious, aboveground defects."

   Details of conditions to be assessed may also be included in the scope of work. For example, trees often have small, dead branches throughout the crown, but the tree risk manager is primarily concerned about larger branches that can result in serious consequences if they fail. Assessment specifications may state that only branches greater than 2 in (5 cm) in diameter should be identified in the assessment. Similarly, details can be specified for the minimum degree of lean, live crown ratio, degree of taper, or other conditions of concern.

3. **Time frame.** The time frame is the period for which an assessment is defined. It is the specified length of time for which the assessor is considering the likelihood of failure and impact. The time frame is usually decided with or specified by the tree risk manager.

4. **Reporting.** The manner of reporting and any additional documentation should be defined. The preferred reporting method is a

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written report. In some instances, however, the report may be oral. Oral reports should be followed up with a written report, when appropriate. If a written report is to be presented to someone other than the person who contracts with the tree risk assessor, that person or agency should be identified.

Nelda Matheny

Figure 1.8 Most tree structural failures involve a combination of structural defects or conditions, such as the presence of decay or poor structure, and an unusual or extreme loading event, such as strong wind.

5. **Timetable for assessment and reporting.** When an assessment (site visit) will be conducted and the due date for the report should be specified.

Determining the Time Frame

The **time frame** (the period for which an assessment is defined) is included in the scope of work. The tree risk manager may specify the time frame, or it may be agreed upon by the tree risk assessor and tree risk manager.

Time frames of one to five years are common. When defining a time frame, tree risk managers and assessors should consider that factors such as site and tree conditions may change over time. The longer the time frame, the more factors may change and the greater the uncertainty.

As the time frame increases beyond three years, uncertainty associated with the likelihood of failure may increase beyond what is reasonable. When this happens, there may be a tendency to increase ratings which, in turn, may lead to unnecessary mitigation.

Assessments may also be conducted for different time frames. For example, tree risk may be assessed for both a one-year time frame and a three-year time frame. Producing risk ratings for multiple time frames can sometimes help a tree risk manager choose among mitigation options.

Choosing an unreasonably long time frame to justify tree removal or excessive pruning is unethical.

The Tree Risk Assessment Process

Tree risk assessment provides information about the level of risk posed by a tree over a specified time frame. This is accomplished in qualitative tree risk assessment by categorizing the likelihood of failure and impact, then categorizing the consequences of a tree failure. These factors are used to determine the level of risk. An overview of the basic tree risk assessment process can be summarized as follows:

1. Agree on the scope of work.
2. Identify potential targets.

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3. Assess the site for factors that could contribute to or mitigate risk.
4. Evaluate tree and site conditions that may lead to failure, the potential loads on the tree, and the tree's adaptations to weaknesses to categorize the likelihood of failure.
5. Assess the likelihood that a tree could strike people and/or property or disrupt activities to categorize likelihood of impact.
6. Evaluate the potential for harm to each target to categorize the consequences of failure.
7. Report findings, including mitigation options and their associated residual risks, and reassessment recommendations.

Details about this process are provided later in this manual.

Professional Responsibilities

When undertaking a tree risk assessment, assessors have responsibility for their opinions and recommendations. Assessment reports will be used as the basis for decisions regarding public safety, as well as the possible impacts to buildings and other structures. The work may be reviewed by insurance professionals, lawyers, and the courts.

Maintaining professional **ethics** and integrity is essential. Assessments should be impartial and objective, with conclusions based on facts, observations, and analyses. Tree risk assessors have a duty to maintain independence and to avoid conflicts of interest. If the assessor or their employer provides arboricultural services that might be recommended as mitigation measures, the assessor should disclose this information to the client and ensure that their assessment and recommendations are independent of any other potential service.

There may be times when the assessor recognizes that they do not have the appropriate skills or equipment to undertake advanced risk assessments. Examples include conducting a heartwood decay assessment, climbing a tree for aerial assessment, or performing a detailed root examination. In such situations, the assessor should reserve judgment and, if approved by the client, bring in a specialist who can provide those services.

Many countries and some jurisdictions in the United States have passed legislation that addresses who is responsible for maintaining trees. In other places, courts base their rulings on **legal precedents**—similar cases that have been decided in the past. Risk managers should be aware of the applicable country, state, and local regulations.

When evaluating a claim or lawsuit, courts consider the **duty of care** and the standard of care. The duty of care is a legal obligation to take reasonable actions to protect others from harm. Generally, the duty of care for a tree owner is to provide a reasonable degree of safety for people and property near their trees. The duty of care for a tree risk assessor is to use the generally accepted **standard of care** (as defined in applicable standards, best management practices, qualifications, and training courses) when performing work.

The standard of care is the degree of care that a reasonably prudent person should exercise under the same or similar circumstances. If a person's conduct falls below such a standard, that person may be liable for injuries or damages resulting from their conduct. Whether the duty of care has been met is judged by examining if the standard of care was implemented. Failure to act reasonably under the circumstances is a **breach of duty** of care and may constitute negligence. **Negligence** is failure to use reasonable care, resulting in damage or injury.

In legal matters, the testimony of expert witnesses is often used to establish the standard of care. Also considered is the customary practice in the field. Ultimately, courts determine whether individuals acted in a reasonably prudent manner under a given set of circumstances. If a person's conduct falls below the standard of care, and that breach of duty results in harm, they may be held liable for the damages or injuries.

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CASE STUDY

Scope of Work

The risk manager for a woodland park with both natural areas and group picnic facilities wanted to conduct a tree risk assessment as part of a comprehensive tree risk management program for the park system.

The risk manager met with an arborist qualified to perform tree risk assessments to discuss how to design and implement a program that would meet their duty of care. They discussed what tasks and level of assessment would be reasonable and proportionate for the various use areas in the park. The park contained hundreds of trees, but not all had targets that could be damaged if tree failure occurred. Furthermore, some target areas had greater use than others, and the consequences of failure varied. The trees were highly valued for their ecological benefits, use by wildlife, and their recreational and health benefits to the visiting public.

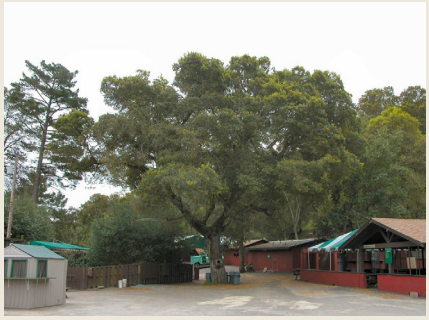
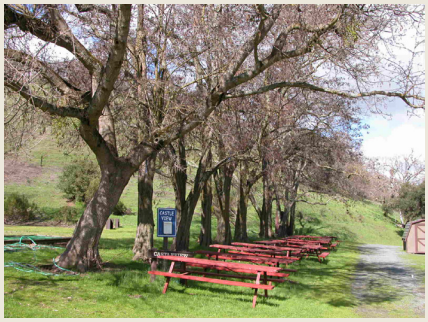
The risk manager and tree risk assessor worked together to develop a framework for the tree risk assessment, a scope of work, and a contract. They identified the method, level, and details of the assessment, the area to be assessed, a time frame for the assessment, targets of concern, their occupancy rates, and a timetable for the project.

The framework for the tree risk assessment identified the methods of assessment, targets of concern, and time frame:

- They decided to apply the methodology defined in the ISA BMP—*Tree Risk Assessment*, performing a basic tree risk assessment (Level 2) of every tree in several defined areas.
- The areas defined for tree risk assessments would be near park facilities, structures, and recreational areas that were most heavily used by the public. Natural areas and remote hiking trails would not be assessed due to the very low likelihood that a person would be struck by a falling tree or branch.
- Targets to be considered include: 1) people using structures, trails, picnic areas, play areas, access routes, parking areas, and/or other park facilities; 2) vehicles on defined roads and in parking lots; and 3) park structures.
- The time frame for the risk assessment was established as one year.

The risk manager and risk assessor created a scope of work that included the following:

1. Identify and map the assessment areas where the targets of concern (people, vehicles, and structures) are within a distance of the height of adjacent trees (1 × height of tree).
2. Tag and map the location of each tree within the assessment areas.

Photos: The woodland park had a range of intensity of use areas, including buildings and parking areas (left), designated picnic areas (middle), and trails (right).

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3. Perform a basic tree risk assessment (Level 2, ISA BMP—*Tree Risk Assessment*) of every tree in the assessment area and, where decay is suspected, sound the lower trunk and buttress roots with a mallet.
   a. Assess and categorize the likelihood of failure within a one-year time frame.
   b. Assess and categorize the likelihood of each failed part impacting a person, vehicle, or structure.
   c. Assess and categorize the potential consequences of tree failure and impact according to the guidelines provided by the risk manager for each failure type/target combination.
   d. Determine the risk ratings for each failure type/target combination.
   e. Determine the overall risk rating for each assessed tree.
      The manager determined that the risk would be mitigated if it exceeded the threshold, defined by the risk manager as *moderate* risk. The tree risk assessor would therefore:
   f. Provide mitigation options for each tree with a *moderate* or higher tree risk rating.
   g. Determine residual risk for each tree.
   h. Recommend reassessment intervals for each area based on residual risk ratings, targets, and occupancy rates.
4. The tree risk assessments will begin upon approval of contractual agreements and be completed within 60 days.
5. The tree risk assessor will develop and submit a written report of their findings to the risk manager within 75 days of contract approval.
6. If a tree is identified as a *high* or *extreme* risk, the tree risk assessor will immediately inform the risk manager.

The contract for the work was approved, and the work proceeded. The tree risk assessor completed the work and submitted the report to the tree risk manager. The tree risk assessor was paid for their professional services. The tree risk manager went on to develop another contract for pruning, support system installation, and tree removal for trees identified by the tree risk assessor as *moderate* risk or higher where mitigation would result in a residual rating of *low*.

Photos by Nelda Matheny

Because TRAQ-qualified tree risk assessors are considered experts in tree risk assessment, they can be held to a higher standard for recognizing hazards and assessing risk than those who do not hold similar credentials. The standard of care for a tree risk assessor is what a reasonable tree risk assessor would do under similar circumstances. This manual will help guide the assessor through those practices.

Risk assessment involves making professional judgments based on observations and data that are not as complete or detailed as we might like. All estimates of risk must be based on the best available observations and data.

Uncertainty is associated with tree risk assessment because of the limited ability to predict biological processes (e.g., rate of progression of decay, response growth), soil conditions, weather events, occupancy rates, and potential consequences of tree failure. An assessor should understand sources of uncertainty and communicate them to the tree risk manager.

Conducting a tree risk assessment neither ensures nor requires perfection. The tree risk assessor, however, does have the responsibility to perform the work agreed to in the scope of work and to meet professional standards of practice.

Safety

There may be occasions when a tree risk assessor will be exposed to hazardous conditions. Examples include assessing trees when hazards exist at the site and during or after a wind or ice storm. When the assessor discovers a hazard, they should avoid it.

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Figure 1.9 Maintain a safe distance when assessing trees near power lines during and after storms that may cause branches to contact utility wires. The utility company should be notified if there is risk of electrical contact.

Caitlin Littlejohn

Figure 1.10 Perform a preclimb inspection before any aerial tree risk assessment.

In adverse weather conditions (e.g., strong winds, snowfall, freezing rain), it may be advisable to postpone the assessment.

The tree risk assessor should identify hazards at the site prior to starting the assessment. Hazards include branches that are severed or broken and hanging aloft; branches in contact with electric utility wires; steep slopes; unstable soil; and downed electric wires. In some cases, the tree risk manager will need to be notified so that the hazard can be mitigated prior to or after the assessment.

The tree risk manager should communicate any identified hazards to crews working on the site or tree. Tree workers approaching a tree should also conduct their own worksite inspection before entering the site. If the tree or tree part cannot support the additional load of the climber or rigging, work should be performed from an aerial lift or crane.

Whenever a tree is to be climbed for an advanced aerial assessment, the arborist should conduct a preliminary hazard assessment of the tree and site prior to climbing (preclimb inspection).

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Summary

Tree risk assessment is the systematic process used to identify, analyze, and communicate tree risk. It is a subset of tree risk management. An understanding of the basic terminology and fundamental concepts of tree risk assessment provides the foundation upon which assessors build knowledge and experience. As assessors work through this manual, they will learn about the levels of assessment and become familiar with the methods and techniques used to assess tree risk. The assessor should be aware of the legal, ethical, and safety issues involved in tree risk assessments. In managing trees, the risk manager should strive to strike a balance between the risk that a tree poses and the benefits it provides.

Key Concepts

1. It is impossible to maintain trees free of risk; some level of risk must be accepted to experience the benefits that trees provide.
2. In assessing and managing trees, the tree risk manager needs to balance the risk that a tree poses against the personal, societal, and ecological benefits that it provides.
3. Tree risk managers are advised to consider what is reasonable and proportionate to the specific conditions and situations before deciding whether a tree risk assessment is required or what level of assessment is appropriate.
4. Tree risk managers and tree risk assessors have different roles and responsibilities. They should communicate about the tree risk assessment assignment and results.
5. The two primary approaches to risk assessment are quantitative and qualitative. Only qualitative approaches are used for individual trees.
6. Terminology is important. Arborists should understand and communicate the differences among the terms tree risk assessment, tree inspection, and worksite inspection to avoid misunderstandings.
7. Prior to beginning a tree risk assessment, it is important to work with the client to define the scope of work.
8. Risk assessment requires a strong sense of professional responsibility. The duty of care for a tree risk assessor is to use the generally accepted standard of care (as defined in applicable standards and best management practices) when evaluating tree risk.
9. There may be times when the assessor recognizes that they do not have the appropriate skills or equipment to undertake some aspects of the risk assessment process. In such situations, the assessor should reserve judgment and, upon approval of the client, bring in a specialist who can provide those services.
10. There may be occasions when the assessor will be exposed to hazardous conditions when inspecting a tree. Assessors must be aware of risk to themselves and others and take appropriate precautions. When practical, tree risk assessment results should be provided to tree workers.

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Overview of Assessing and Categorizing Tree Risk

Risk assessment is undertaken where there are one or more targets of concern that could be impacted by one or more trees, and the tree risk manager thinks that target value, or the possible consequences of tree failure, justifies conducting the assessment.

A tree risk assessment provides information about the level of risk posed by a tree over a specified time frame. In qualitative tree risk assessment, this is accomplished by categorizing the likelihood and consequences of an event.

Steps in Developing a Tree Risk Rating

	Module(s)
Develop a scope of work to define the level and details of the risk assessment, the time frame, and other necessary information. Levels of assessment are: *Limited / Basic / Advanced* • The scope of work is developed by the tree risk manager with input from the tree risk assessor. • The time frame is the specified length of time for which the assessor is considering the likelihood of failure and impact.	**1, 2**
Identify targets, as specified, and categorize the occupancy rate of each. • Categories are: *Constant / Frequent / Occasional / Rare*	**3**
Identify potential failure types and the target zone for each failure type. • The location or way in which failure is likely to occur. (For example: codominant stem on south side or 25 in diameter branch on north side)	**3, 4, 5, 6**
Assess and categorize the likelihood of failure within the specified time frame for each failure type. • Categories are: *Imminent / Probable / Possible / Improbable*	**4, 5, 6**
Assess and categorize the likelihood of tree impacting the target within the specified time frame for each failure type. • Categories are: *High / Medium / Low / Very low*	**3, 4**
For each failure type/target combination, categorize the likelihood of failure and impact (Matrix 1). • Categories are: *Very likely / Likely / Somewhat likely / Unlikely*	**7**
For each failure type/target combination, assess and categorize consequences. • Categories are: *Severe / Significant / Minor / Negligible*	**7**
For each failure type/target combination, categorize the risk (Matrix 2). • Categories are: *Extreme / High / Moderate / Low* • The tree's overall tree risk rating is the highest risk rating determined.	**7**

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Using this publication's methodology, assessors consider three factors and then use two matrices to categorize risk. The factors are the likelihood that the failed tree will impact a target, the likelihood of a tree failure, and the consequences of the failed tree impacting the target.

Likelihood of Impact
The chance of a failure impacting a target within the specified time frame.

Consider
- target zone occupancy
- location in target zone
- protection factors
- direction of fall

Categories
high
medium
low
very low

Likelihood of Failure
The chance of a failure occurring within the specified time frame.

Consider
- site factors
- response growth
- tree health
- tree species
- load
- defects and conditions

Categories
imminent
probable
possible
improbable

Consequences of Failure
Injury, damage, or disruption due to failure.

Consider
- tree or tree part size
- target value/ damage
- protection factors
- fall distance

Categories
severe
significant
minor
negligible

The first matrix combines the likelihood of failure and the likelihood of impact to produce likelihood of failure and impact. The second matrix combines the likelihood of failure and impact with consequences to yield a risk rating.

Matrix 1
Likelihood of Failure
and
Likelihood of Impact

Matrix 2
Likelihood of Failure and Impact
and
Consequences of Failure

Risk Rating

Matrix 1: Likelihood Matrix
The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix
Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

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Levels of Assessment

Module 2

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Levels of Assessment

Module 2

Learning Objectives

- Describe a Level 1 limited visual assessment and explain when it would be used.
- Describe a Level 2 basic assessment and explain how it differs from a limited visual assessment.
- List the common tools that might be used in a basic assessment.
- Discuss the advantages and limitations of each assessment level.
- Discuss how the limitations of a Level 1 limited visual assessment or Level 2 basic assessment might lead an assessor to suggest a higher level of assessment.
- Describe the various Level 3 advanced assessment tools and techniques and explain how they might be used to gather specific information.
- Explain with specific examples why it is important for assessors to understand the possibilities and limitations of the techniques they employ.

Key Terms

advanced assessment
aerial assessment
aerial patrol
basic assessment
clinometer
decay testing
diameter tape
drive-by
ground-penetrating radar (GPR)
hand pull test
level(s) of assessment
LiDAR
limited visual assessment
load-bearing capacity
load testing
mallet
probe
remote sensing/imaging
resistance-recording drill
root collar excavation (RCX)
scope of work
sonic assessment
sonic tomography
static pull test
tree dynamics test
unoccupied aerial vehicles (UAV)
walk-by

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Introduction

Tree risk assessments can be conducted at different levels and may employ various methods and tools. The level(s) should be appropriate for the assignment. The level is specified by the tree risk manager with input from the tree risk assessor.

The ANSI A300 standard for risk assessment and ISA's BMP—*Tree Risk Assessment* define three levels of tree risk assessment:

- Level 1: Limited visual assessment
- Level 2: Basic assessment
- Level 3: Advanced assessment

The level to be employed should be specified in the **scope of work** that is established prior to conducting an assessment. When needed, tree risk assessors should explain the options for **levels of assessment** to clients so that, together, the appropriate assessment level can be established. If, in the judgment of the assessor, risk cannot be adequately assessed at the specified level, the assessor may recommend a higher level of or different assessment. However, the assessor is not obligated to provide a higher level of assessment without additional compensation or modifications to the agreement or contract if it is not within the scope of work for the original assignment. All levels of assessment use the evidence gathered at the time of assessment as the basis for the evaluation of targets, site factors, and/or tree conditions.

In addition to specifying the level of assessment in the scope of work, pertinent details regarding the method should also be specified. For example, a limited visual assessment may be performed by walking by, driving past, or flying above or beside the trees. The method and details applied will greatly influence the cost and reliability of the results.

Standard safe work practices and procedures should be applied for all levels of assessment.

Definitions of Some Key Terms

Several key terms are required for understanding the scope of work and levels of tree risk assessment. Below is a partial list of these terms. A more comprehensive list can be found in the Glossary of Terms.

level of assessment—categorization of the breadth and depth of the assessment and risk analysis; may be level 1, 2 or 3.

limited visual assessment (Level 1)—a visual assessment from a specified perspective of an individual tree or a population of trees near specified targets to identify specified conditions or obvious defects.

basic assessment (Level 2)—a ground-based, visual assessment of a tree and its surrounding site, and a synthesis of the information collected.

advanced assessment (Level 3)—an assessment to provide information about specific tree parts, defects, targets, or site conditions beyond what is included in a basic assessment.

scope of work—the defined project objectives and requirements; a description of the specific work to be performed for specific trees, schedule, and reporting method(s).

Level 1: Limited Visual Assessment

A Level 1 **limited visual risk assessment** is a visual assessment from a specified perspective of an individual tree or a population of trees near specified targets to identify specified conditions or obvious defects. Limited visual assessments are the fastest but least thorough means of assessment. They are intended primarily for quick assessment of many trees and can be useful for tree managers faced with budgetary constraints.

When conducted by trained professionals, limited visual assessments can often provide tree managers with adequate information to accomplish their risk management goals. These assessments are often done on a specified schedule and/or may be done immediately after storms to rapidly assess a tree population.

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Table 2.1 Summary of levels of tree risk assessment.

	Level 1: Limited Visual	Level 2: Basic	Level 3: Advanced
Description:	A visual assessment from a specified perspective of an individual tree or a population of trees near specified targets, to identify specified conditions or obvious defects	A ground-based, visual assessment of a tree and its surrounding site and a synthesis of the information collected	An assessment to provide information about specific tree parts, defects, targets, or site conditions beyond what is included in a basic assessment
Methods/ details:	May be conducted by walking, driving, aerial patrol, or remote sensing/images	Inspect completely around the tree trunk looking at the visible aboveground roots, trunk, branches, and site	Various options (e.g., aerial assessment, detailed target analysis, detailed site evaluation, decay testing, wind load analysis, load testing)
Equipment:	May include vehicle, aerial photography, remote sensing equipment	May use simple tools for measuring trees and acquiring more information (e.g., binoculars, mallet, probe)	Specialized tools or techniques are applied
Risk rating created?	Not necessarily	Yes	No; results may modify basic assessment risk rating
Limitations:	Limited to obvious conditions. Some conditions may not be visible from an assessment of one side of a tree; observations may be limited by foliage, structures, snow accumulation, vines or other plants, soil, or mulch	Limited to conditions visible from ground-based assessment. Some internal, below-ground, or upper-crown conditions may not be detected; observations may be limited by foliage, structures, snow accumulation, vines or other plants, soil, or mulch	Limited to specific conditions for which the assessment is designed; all technologies have limitations and involve uncertainty

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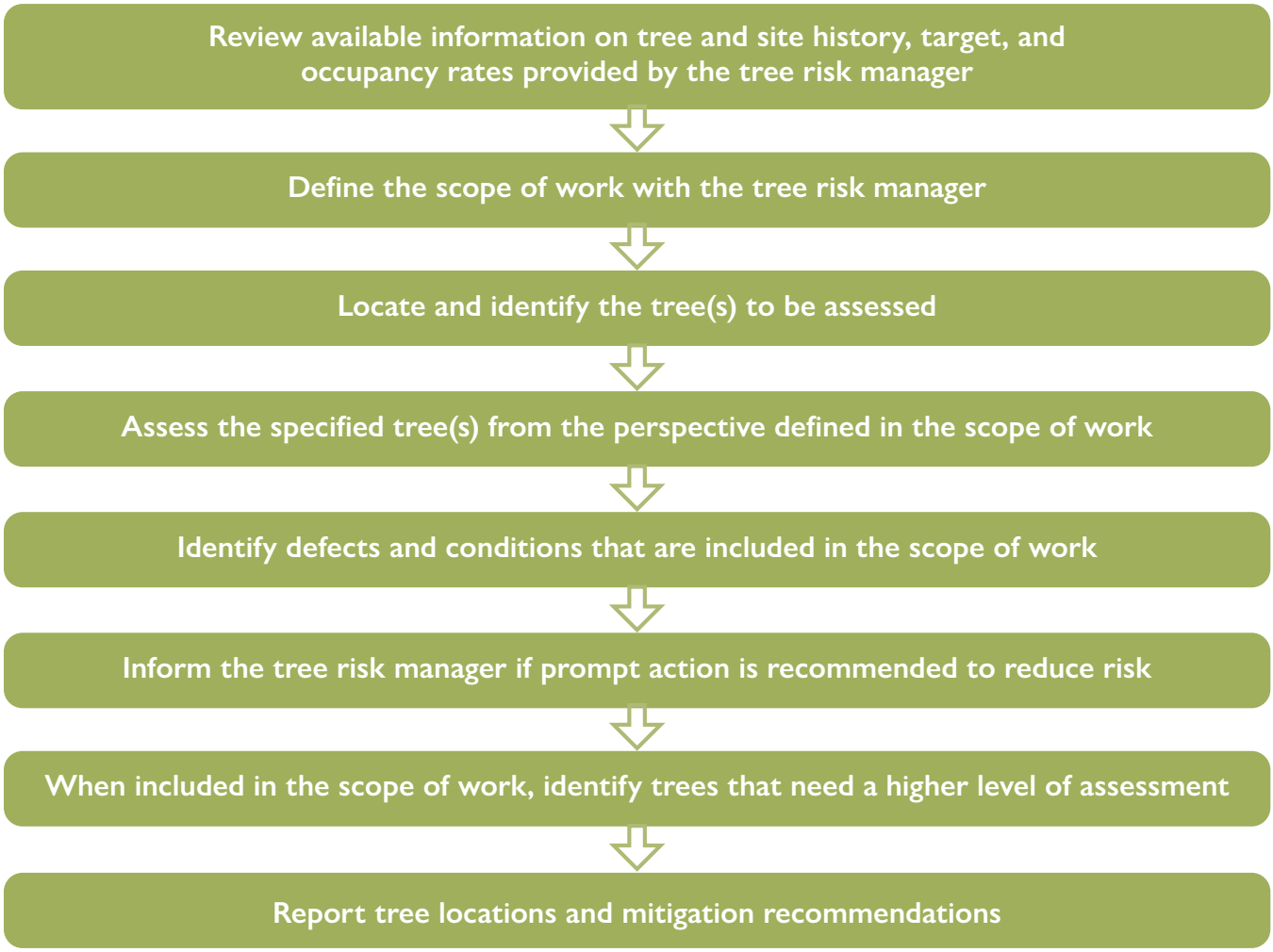

Figure 2.1 Flow chart of a Level 1 limited visual assessment.

Typically, the specified conditions or obvious defects include dead trees, large cavity openings, large dead or broken branches, fungal fruiting structures, large cracks, and/or severe or uncorrected leans. In addition, the tree risk manager may specify certain conditions of concern, such as lethal pests or symptoms associated with root decay.

The perspective of assessment may include one or more of the following:

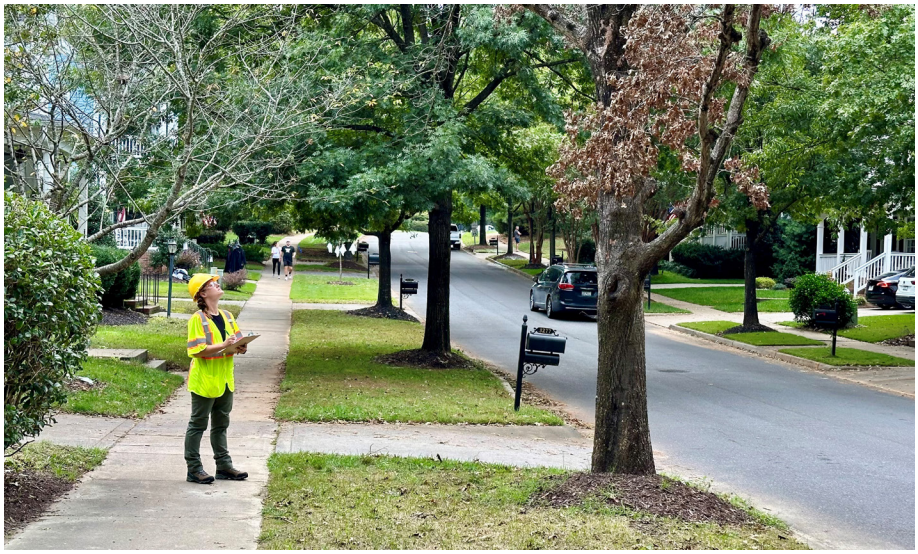

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Figure 2.2 Walk-by is a limited visual assessment of one or more sides of the tree, performed as the inspector walks past a tree.

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- **Walk-by** is a limited visual assessment of one or more sides of the tree, performed by the tree risk assessor from a sidewalk or footpath. The tree risk assessor's view may be limited by the site (e.g., slope, vegetation) or by the need to stay on the sidewalk or footpath, on public property, or within a right-of-way.
- **Drive-by** (windshield) is a limited visual assessment of one side of the tree, performed from a moving vehicle that is appropriate for the site and scope of work. This type of assessment is often performed by municipalities, utilities, or other agencies or landowners who have a limited budget but need to inspect many trees.
- **Aerial patrol** is a limited visual assessment made from aircraft, **unoccupied aerial vehicles (UAVs)**, or satellites above street trees, utility rights-of-way, other specified areas, or individual trees. This type of assessment is conducted by some electric utility companies or their contractors. Sometimes a more detailed, ground-based assessment may be specified to confirm observations. Flight images are often recorded to document observations.
- **Remote sensing/imaging** can be used as limited visual assessments. These include the use of Light Detection and Ranging (LiDAR), aerial photography, satellite images, and the assessment of Google Street View™ images.[1] These technologies provide data and images of trees relative to potential targets and conflicts (e.g., streets, structures, power lines).

E. Thomas Smiley

Figure 2.3 Drive-by is a limited visual assessment of one side of the tree, performed from a slow-moving vehicle.

The Asplundh Tree Expert Company

Figure 2.4 Aerial patrol assessments are made from an aircraft overflying utility rights-of-way or other large areas.

When a tree of concern is identified, specific information about that tree should be recorded. At a minimum, this information includes the tree location. In addition, it may include the species, tree size, defect or condition identified, photographs, recommended remedial action, risk rating, or work priority. A higher level of assessment may also be

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Julian A. Dunster

Figure 2.5 A limitation of Level 1 (limited visual) assessments is when trees are viewed only from one perspective. Major defects can be missed, as illustrated by the two different views of the same tree shown here.

recommended or conducted if that option is included in the scope of work. The tree risk assessor should promptly inform the tree risk manager if a tree is identified as needing immediate actions to avoid harm.

In a limited visual assessment, the scope of work may not require a tree risk rating, but it may require a work priority or mitigation recommendation.

If tree risk ratings are required for a population of trees, one or two of the three factors assessed (likelihood of failure, likelihood of impact, severity of consequences) are typically held constant. For example, if assessing street trees, the likelihood of impact and the consequences of failure might be assumed to be the same for each tree on a residential block, and, therefore, the assessor would only need to determine each tree's likelihood of failure.

The limited visual assessment report should include the tree location and additional information that is specified in the scope of work. The report may exclude information about trees without significant defects or those that do not have specified defects or conditions. The scope of work may, in some cases, specify that the assessor further assess a tree or record images to verify or document observations without elevating the assessment to a basic assessment. Limited visual assessments are sometimes used to determine which trees require further assessment at the basic or advanced levels, after which an appropriate mitigation can be recommended.

An advantage of limited visual assessments is that they can be used as a relatively quick screening tool for assessing large populations of trees. In some cases, recommended mitigation will be clear; for example, remove a dead tree or provide clearance for the electric transmission line. In other cases, however, it will not be possible to make recommendations without further inspection. When trees of concern are identified, a basic assessment might be recommended to provide additional information. The scope of work should address whether recommendations for higher levels of assessment are to be included.

A limitation of a limited visual assessment is that only obvious conditions that are seen from the specified perspective on the day of the assessment are included. Internal, belowground, or upper-crown conditions, as well as certain types of decay, may be impossible to see. Some conditions may not be visible from an inspection of one side of a tree and some conditions are not visible throughout the year. Observations may be limited by foliage, structures, snow accumulation, vines or other plants, soil, or mulch. A Level 1 risk assessment may not be adequate to recommend risk mitigation measures.

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CASE STUDY

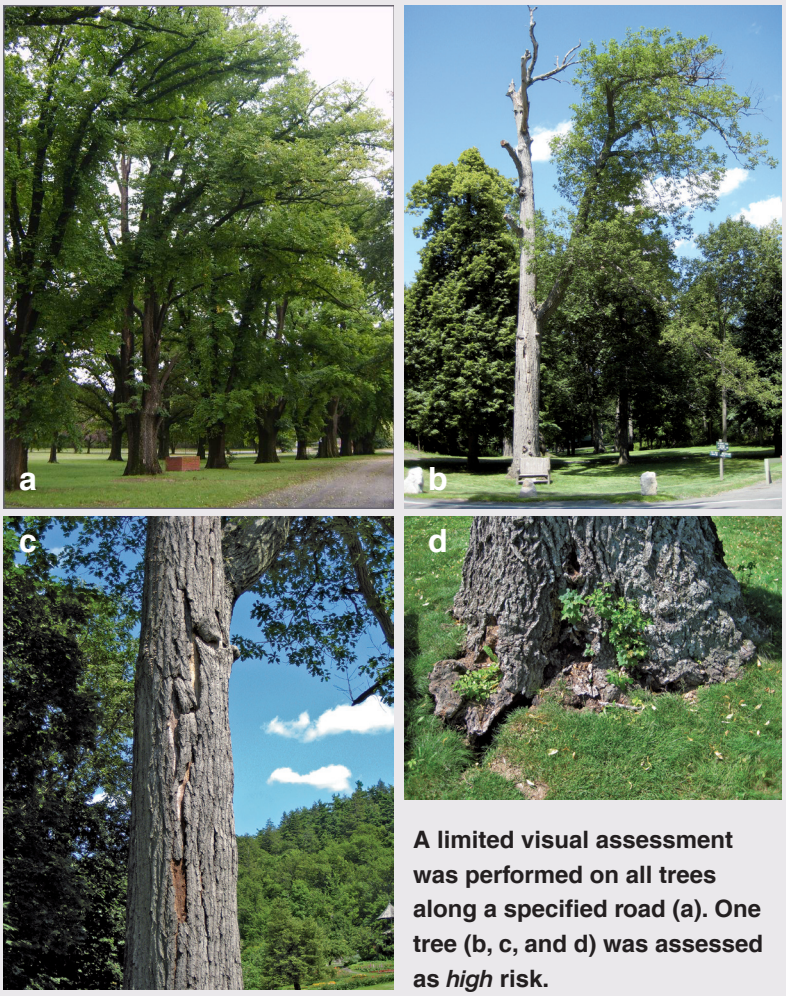
Holding Factors Constant in a Level I Assessment

Assignment: Perform a limited visual assessment for all trees along a specified section of road and report any trees with a risk rating of *moderate* or higher.

As specified in the scope of work, the tree risk assessor viewed the trees from the road (walk-by).

Time Frame: Three years.

Targets and Site: Targets were defined by the city's tree risk manager as pedestrians, people in vehicles on the road, and the vehicles driving on the road. Roadside parking was not permitted, so all targets are mobile. Some pedestrians walk by the trees daily, but only during the workday and not on the weekend. Many vehicles drive on the road during the day; there are fewer at night and on the weekends.



A limited visual assessment was performed on all trees along a specified road (a). One tree (b, c, and d) was assessed as *high* risk.

Since this was a limited visual assessment, the assessor decided it was reasonable to keep the likelihood of impact and severity of consequences constant for each target. Pedestrians have *occasional* occupancy in the target zone, so the likelihood of impact was *low*. Pedestrians were unprotected, so the consequences of failure were *severe*. Vehicles had *frequent* occupancy so the likelihood of impact was *medium*. The consequences of failure were *significant.* For people in vehicles, the likelihood of impact was *medium* and the consequences of failure were *severe*. Before doing the walk-by risk assessment, the assessor prepared a worksheet that included each target and its likelihood of impact and consequences already filled in (because they were kept constant).

Tree Conditions and Analysis: Each of the trees along the road was assessed for likelihood of failure. Except for a single tree, the likelihood of failure rating was either *possible* or *improbable*. When combined with *low* or *medium* likelihood of impact ratings, *possible* and *improbable* likelihood of failure ratings yielded *unlikely* likelihood of failure and impact rating (from Matrix 1). When combined with *severe*

Target	Likelihood of failure	Likelihood of impact	Likelihood of failure and impact (Matrix 1)	Consequences	Risk rating (Matrix 2)
Pedestrians		*low*		*severe*	
People in vehicles		*medium*		*severe*	
Vehicles		*medium*		*significant*	

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or *significant* consequences of failure, an *unlikely* likelihood of failure and impact rating yielded a risk rating of *low* (from Matrix 2).

The single tree that did not have an *improbable* or *possible* likelihood of failure rating was a 42 in (107 cm) diameter pin oak (*Quercus palustris*). The road curved around the tree on three sides and there was a bench at the tree's base. When viewed from the sidewalk, the assessor could see a dead top above a large, living branch. They could also see a 10 ft (3 m) long crack in the trunk below the branch attachment. In addition, there was an open cavity at the base of the trunk and dead roots were separated from the soil.

The pin oak with basal decay was rated with an *imminent* likelihood of failure.

- When combined with the *low* likelihood of impact for pedestrians, the likelihood of failure and impact was *somewhat likely* (from Matrix 1). When combined with the *severe* rating for consequences, the risk rating was *moderate* (from Matrix 2).

Tree #47—Pin oak

Target	Likelihood of failure	Likelihood of impact	Likelihood of failure and impact (Matrix 1)	Consequences	Risk rating (Matrix 2)
Pedestrians	*imminent*	*low*	*somewhat likely*	*severe*	*moderate*
People in vehicles	*imminent*	*medium*	*likely*	*severe*	*high*
Vehicles	*imminent*	*medium*	*likely*	*significant*	*high*

- When combined with the *medium* likelihood of impact for people in vehicles, the likelihood of failure and impact was *likely* (from Matrix 1). When combined with the *severe* rating for consequences, the risk rating was *high* (from Matrix 2).
- When combined with the *medium* likelihood of impact for vehicles, the combined likelihood of failure and impact was *likely* (from Matrix 1). When combined with the *significant* rating for consequences of failure, the risk rating was *high* (from Matrix 2).
- The overall tree risk rating–the highest rating for the tree–was *high*.

Reporting: The risk assessor reported the high-risk tree to the risk manager by phone at the end of the day, and they mailed a written report of all results a week later.

The tree risk manager scheduled a crew to remove the pin oak the next day.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photo "a" by Doug Sharp. Photos "b, c, and d" by Jerry Bond.

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Level 2: Basic Assessment

A Level 2 **basic assessment** is a ground-based, visual assessment of a tree and its surrounding site, and a synthesis of the information collected. In a basic assessment, a tree risk assessor inspects all the way around the tree, looking at the site and visible tree parts. This is the level of assessment commonly performed in response to a tree risk manager's request for individual tree risk assessment.

A basic assessment may include the use of simple tools to gain information about the tree or defects. Use of simple tools is not mandatory unless specified in the scope of work. Use of these tools does not elevate an assessment to a Level 3 advanced assessment.

Simple tools include the following:

- Measuring devices (e.g., **diameter tape**, **clinometer**, tape measure), and cell phone apps (e.g., light, angle gauge, camera, map) are used to collect data.
- Binoculars may be used to inspect the upper portions of a tree's crown to look for cavities, nesting holes, cracks, weak unions, and other conditions and growth responses. A basic assessment does not include climbing the tree, so binoculars can often provide a closer look without needing to leave the ground.
- A **mallet** may be used to tap (sound) trees to detect tonal variations that may indicate hollow areas, sapwood decay, or dead bark (Figure 2.6).

  An internal cavity that has a thin wall will typically produce a deeper, more resonating sound than a solid stem. Dead bark will make a clapping sound when it is tapped. Sounding will not always reveal internal issues. Areas of decay deep within the heartwood or in roots may not be revealed by sounding. Sounding with a mallet is useful in judging whether and where to perform more advanced assessments.

  Experience with interpreting tonal variations using sounding techniques will lead to greater proficiency and reliability.

- A **probe** is a stiff, small-diameter rod, stick, or wire that can be inserted into a cavity to estimate its size and extent (Figure 2.7). Probes may also be used to identify the presence or depth of structural roots.

  A probe can be used anywhere there is an opening in the tree; the resistance met in probing can help an assessor detect deteriorated wood. However, because not all openings will be accessible and there may be sections of decayed wood adjacent to a cavity that cannot be differentiated from nondecayed wood, using a probe gives only an approximation of the extent of decay. Tapping around the opening with a mallet prior to probing can prevent unintended encounters with wildlife inside the cavity. Wildlife in a cavity should not be disturbed.

- Digging tools such as a trowel or other hand tool can be used to scrape away surface soil to expose surface roots or the root collar. Take care not to damage roots during the excavation process. A more extensive root

E. Thomas Smiley

Figure 2.6 Sounding. Strike the tree with a mallet and listen for tonal variations that indicate dead bark or internal hollows.

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E. Thomas Smiley

Figure 2.7 Probing. Use a stiff, small-diameter rod to probe into cavity openings to estimate their size.

A limitation of a basic assessment is that it includes only conditions that are detected from a ground-based assessment on the day it was performed. Some internal, below-ground or upper-crown conditions, as well as certain types of decay, may be impossible to see or detect. Observations may be limited by structures, access limitations, snow accumulation, vines or other plants, soil, or mulch.

Often a basic assessment is adequate for assessing risk and making recommendations, but it sometimes reveals the need for an advanced assessment.

collar excavation is a Level 3 advanced assessment.

- A compass can be used to determine the orientation of the tree, site, and defects or conditions noted on the tree(s) being assessed. There are many smartphone and tablet apps that include a compass, as well as the means to determine tree height and trunk lean.
- Using a camera to take photographs to document conditions that are observed is usually a good idea. A camera can also be used to "zoom in" to better observe conditions in the tree crown.

A tree risk rating is usually developed in a basic assessment. A basic assessment also includes mitigation recommendations and, as appropriate, a residual risk rating, recommendation for advanced assessments, and need for reassessments. This information should be reported as specified in the scope of work.

An advantage of a basic assessment over a limited visual assessment is that each tree is inspected more closely and from all sides, increasing the amount of information and detail that can be observed and/or measured.

E. Thomas Smiley

Figure 2.8 Excavation. Simple tools can be used to conduct shallow excavations to expose the root collar or roots at the soil surface. Take care not to damage roots during the excavation process.

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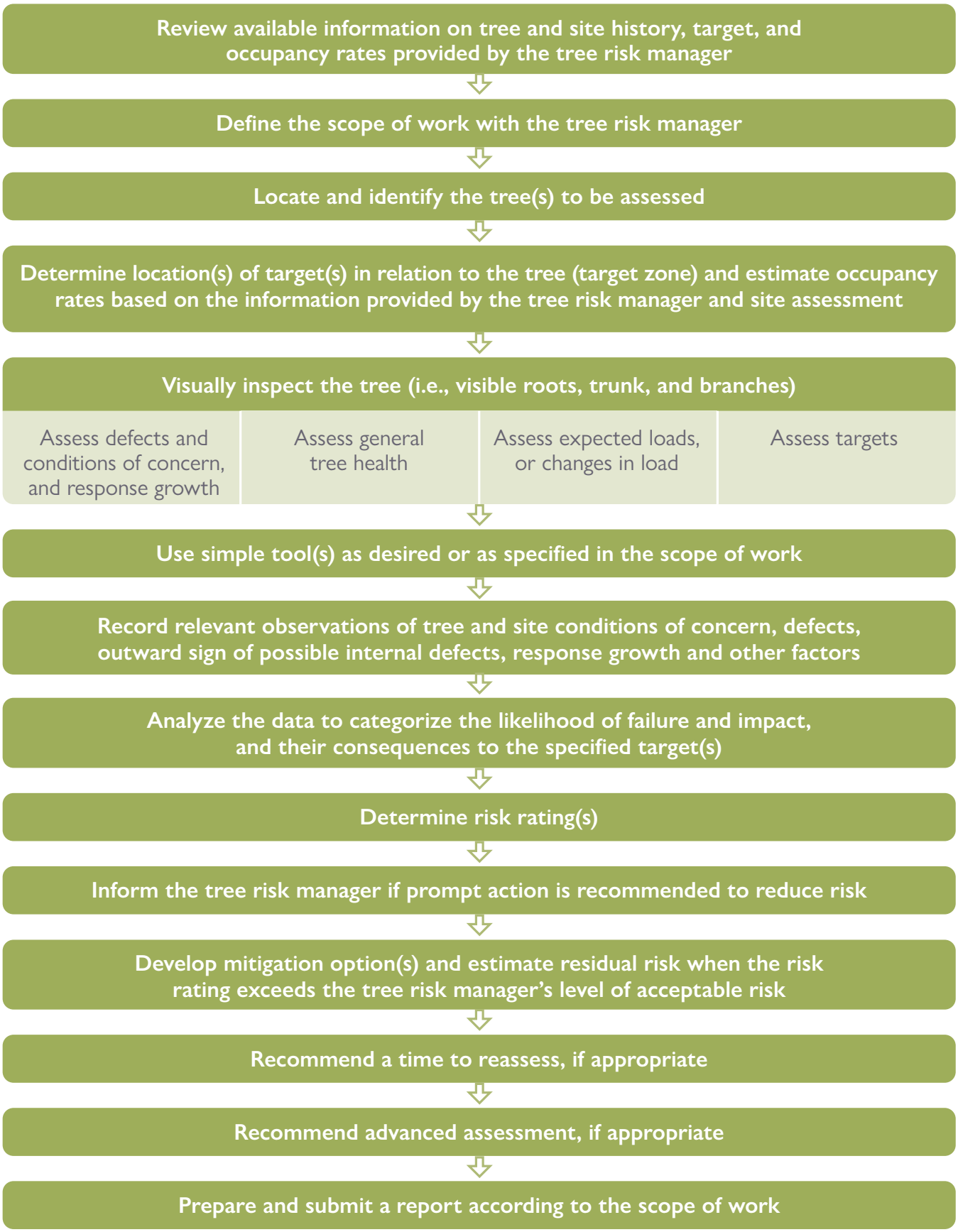

Figure 2.9 Flow chart of Level 2 basic assessment procedures.

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Level 3: Advanced Assessment

A Level 3 **advanced assessment** is performed after or in combination with a basic assessment to provide detailed information about specific tree parts, defects, targets, or site conditions beyond what is determined in a basic assessment. An advanced assessment may provide additional information that could affect the categorization of the likelihood of failure, likelihood of impact, or consequences of failure and impact. In addition, an advanced assessment may increase assessor confidence in the results of a basic risk assessment.

Additional procedures, specialized equipment, data collection and analysis, and/or expertise are required for advanced assessments. As a result, advanced assessments generally take longer and are more expensive.

Procedures and methodologies should be selected and applied as appropriate, with consideration for what is reasonable and proportionate to the specific conditions and situations. The tree risk manager should consider the value of the tree to the owner and community, the possible consequences of failure, and the time and expense needed to provide the advanced assessment. Advanced assessments can provide information that may influence mitigation options such as retention, pruning, or whole tree removal.

There are many types of advanced assessments; some common ones are outlined in the "Level 3: Advanced Techniques" sidebar. Tree risk assessors are cautioned, however, that all technologies have limitations and involve uncertainty. Preference should be given to the least damaging technique if multiple options are equally practical.

The tree risk rating that was developed in the basic assessment may be modified based on the information collected in the advanced assessment. However, tree risk ratings, presentation of mitigation options, residual risk ratings, and future assessment recommendation are not necessarily part of the advanced assessment report.

Most advanced assessment techniques require specialized training and/or equipment. If the assessor lacks the equipment or training, they should seek the assistance of someone who possesses the appropriate equipment and expertise. In addition to the need for technical competency to perform and interpret the assessment, there can be safety issues involved with some advanced procedures.

Advanced assessments are performed to provide information beyond what was determined in a basic assessment about specific tree parts, defects, targets, or site conditions. Many techniques can be considered for advanced risk assessment. A few commonly used assessment methods are described here in more detail.

Aerial Assessment

Aerial assessment (crown assessment) is assessment of the aboveground parts of a tree not visible from a ground-based assessment, including the upper trunk and the upper surfaces of stems and branches. Aerial assessments usually include a visual assessment for defects, conditions, and response growth. Conditions of particular importance include assessment of significant branch unions, cracks in branches, sunscald on the tops of branches, and bark damage from bird or animal activity. In addition, aerial assessments may include evaluation of internal decay.

Aerial assessment can be done from an aerial lift, adjacent building, ladder, unoccupied aerial vehicle, or by climbing the tree. Visual assessment from the ground using binoculars is not considered an advanced assessment, but it may be part of a basic assessment.

Decay Testing

In a basic assessment, it is usually difficult to quantify or estimate the amount and location (i.e., the extent) of internal wood decay. **Decay testing** is any of several advanced assessments that can provide additional information about decay. One method is to send fruiting bodies to a diagnostic laboratory to identify the fungus. Identification may provide

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Level 3: Advanced Techniques

Many techniques can be considered for advanced risk assessment. Some situations may be assessed with multiple techniques. Advanced assessment techniques include the following[1] (in alphabetic order):

- Aerial assessment and evaluation of structural defects higher in the crown
  - visual inspection from (1) within the tree crown, (2) a ladder, or (3) an aerial lift
  - unoccupied aerial vehicle (UAV) photographic inspection
  - decay and response growth testing of branches
- Decay testing
  - diagnostic analysis for fungal identification
  - hand drilling
  - resistance-recording drilling
  - increment coring
  - sonic tomography
  - pulsed electrical current meter/tomography
- Detailed site evaluation
  - land use history evaluation
  - soil profile inspection to estimate root depth
  - soil type assessment
- Detailed target analysis
  - property value
  - use and occupancy statistics
  - potential disruption of activities
- **Load testing**
  - hand pull
  - measured static pull
  - measured tree dynamics
- Mathematical/computer modeling of loss in load-bearing capacity
  - formulas to estimate the effect of decay
  - computer models and apps to estimate tree stability or loss in load-bearing capacity
  - measuring and assessing the change in trunk lean
  - direct stem lean measurement
  - 3D stem scans and interpretation of point clouds
  - analysis of calibrated stem pictures
- Root assessment
  - root and root collar excavation
  - root decay evaluation
  - ground-penetrating radar
- Storm/wind load analysis
  - detailed assessment of tree exposure and protection
  - computer-based estimations according to engineering models
  - wind reaction monitoring over a defined interval
- Tree health evaluation
  - tree ring analysis (in temperate zone trees)
  - shoot length measurement
  - detailed health analysis (e.g., color evaluation, water potential, chlorophyll fluorescence)
  - starch assessment
- Weather analysis
  - wind rose chart
  - historical storm data

1 Inclusion of specific techniques in this list should not be considered an endorsement of those techniques.

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Figure 2.10 Aerial assessment (crown assessment) involves the aboveground parts of a tree, especially those not visible from the ground. In this photo, the assessor is also drilling as part of decay assessment, another Level 3, advanced assessment, technique.

information about the type of decay and expected rate of spread. If it is necessary to accurately determine the extent of decay, an assessor can use one of several decay-detecting techniques. Instruments and techniques differ in precision, resolution, reliability, and cost. Two well-established technologies include drilling and the use of sonic devices.

Drilling

Three types of drilling tools are used to evaluate the extent of decay: a handheld drill, a **resistance-recording drill**, and an increment borer. All can distinguish between solid and decayed wood by the resistance to penetration as the drill bit moves through the wood. It is important to carefully select testing locations so that the size and configuration of the decay column can be estimated. Before testing, the best location to test should be determined by sounding, visual assessment, or both. The tree risk assessor should conduct sufficient testing to estimate the approximate extent of the decayed area. However, the tree risk assessor should avoid unnecessary or excessive wounding. Tree risk assessors should also consider that drilling into decay can breach CODIT walls (most importantly wall 4), which may allow decay to spread. The number of drillings should be as few as possible but as many as needed.

One type of drilling device is a handheld cordless electric drill fitted with a long (8 to 18 in [20 to 45 cm]), small-diameter (1/8 in [3 mm]), full-fluted drill bit (Figure 2.12). This technique is primarily limited to detecting advanced stages of decay. Accuracy relies in large part on the experience and expertise of the assessor.

A resistance-recording drill drives a small-diameter (1/8 in [3 mm]) spade bit into the tree (Figure 2.13).

Bartlett Tree Research Lab (subject: Tom Martin)

Figure 2.11 Sometimes it is necessary to collect samples for laboratory analysis. An example is identification of decay fungus so that an assessment can be made of its virulence and expected rate of spread.

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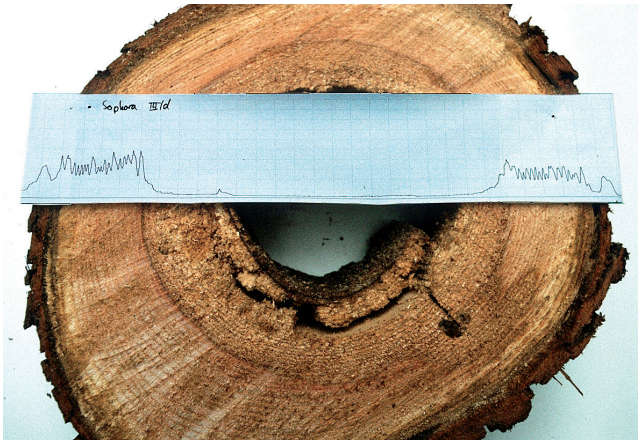
Figure 2.12 Simple handheld electric drills are primarily limited to detecting advanced stages of decay. Assessing decay using this technique relies in large part on the experience and expertise of the operator.



Frank Rinn

Figure 2.13 Incipient decay, effectiveness of compartmentalization, and response growth rates may be estimated from profiles created by some high-resolution resistance drills. These profiles can be correlated to certain wood density levels and interpreted for information about wood condition.

Julian A. Dunster

Figure 2.14 This tree is being tested using a sonic tomography system.

As the bit penetrates the wood, the resistance to penetration is recorded. With training and experience, an assessor can distinguish solid wood from voids and decay. Incipient decay, effectiveness of compartmentalization, and response growth rates may be estimated from profiles created by some high-resolution resistance drills.

An assessor may also use an increment borer to extract cores from a trunk to evaluate the extent of decay. The core provides a visual record of annual tree ring width and presence of decay. The core can also be submitted for genetic testing to identify the decay fungi in the tree. Increment borers typically have a much larger diameter than bits used for hand drilling and resistance-recording drilling.

Sonic Assessment

Sonic tomography instruments involve the use of stress (sound) waves sent through the wood from one sending/sensor point to other sensor points (Figure 2.14). The time taken to travel through the wood between points is used to create a tomogram, a two-dimensional graphic representation of the data. The tomogram is then interpreted to assess internal wood conditions and see if there is decay, a cavity, or other feature of interest (Figure 2.15). If a crack, cavity, or decay is present, the stress waves travel around the defect, increasing the travel time from the sending point to the receiving point, compared to the time through wood with no defect. The device may not be able to distinguish among decay, cavities, cracks, and included bark. A skilled operator is required to interpret results.

Measuring the travel time between two points can be a quick test only to reveal the presence of cracks or decay between those two points. However, conducting only one test may miss major defects; tests at additional points are needed to provide a

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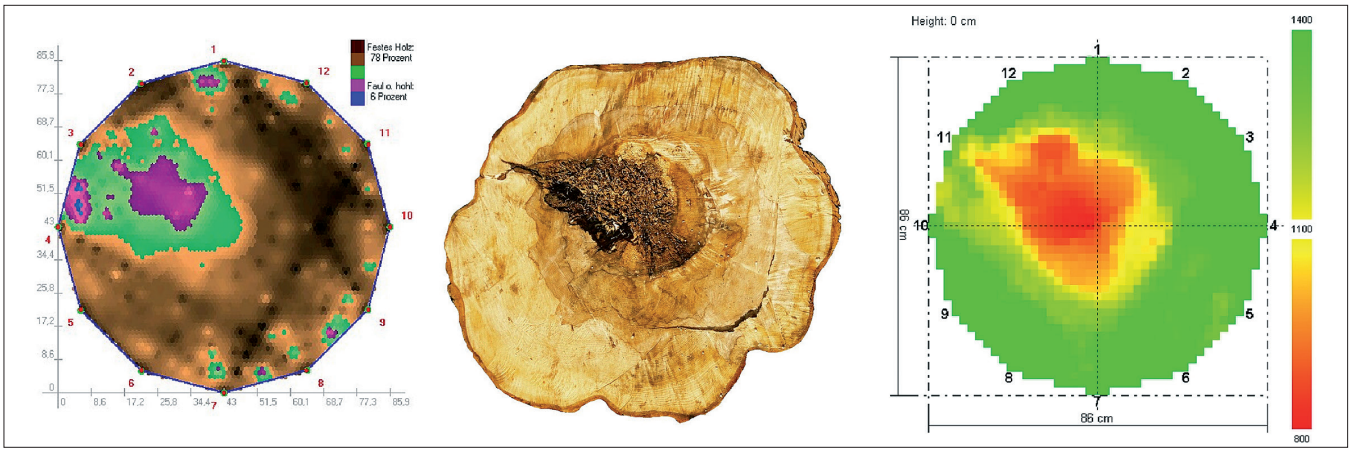

Bodo Sigiert

Figure 2.15 Tomograms derived from sonic tomography tests. Different manufacturers portray the results in different ways, but they all help to determine the presence or absence of internal defects. The center image is the actual tree cross section.

comprehensive assessment. Thus, two sets of points, forming perpendicular lines, are considered the minimum by many assessors to detect large, centrally located defects. The accuracy of a **sonic assessment** is directly related to the size and shape of the stem as well as the placement and number of sensors used.

In contrast to drilling, sonic devices are minimally invasive and are substantially less likely to breach CODIT wall 4.

Detailed Site Evaluation

Advanced methods for site evaluation provide more information about the site, which assessors can use to evaluate the likelihood of failure, tree health, and growing conditions. Examples include researching the site's history and previous land use; inspecting the soil profile to estimate root depth; and collecting soil samples for lab analysis of nutrient content, organic matter, and texture.

Detailed Target Analysis

Advanced assessments can involve a detailed target analysis when more information is needed to refine the occupancy rate, the assessment of the likelihood of impact, or the consequences of failure. Examples of detailed target analysis include searching databases for property value, measuring traffic patterns within the target zone, and quantifying the potential disruption of activities due to tree failure and target impact.

Load Testing

Load tests are used to assist in evaluating the potential for failure. There are several types of load tests: hand pull test, measured static pull test, and measured dynamic test. Load tests do not attempt to detect internal decay; instead, they use deformation or deflection to detect weakness in the structure and assess the load required to initiate the failure process.

A **hand pull test** is a simple test and involves installing a line in the tree and then pulling and releasing the line several times to move the tree or branch (Figure 2.16). When testing root and trunk stability, the line is installed in the crown. When the line is pulled, trunk and root plate movement is observed. Excessive trunk, root, or soil movement may indicate instability. Branches also may be tested in this fashion: the line is run over the branch and pulled, and the tree risk assessor observes branch movement and looks for cracks opening. This technique is sometimes used as part of preclimb assessment. Because the tree or branch reaction is observed rather than measured, tree risk assessors are cautioned against overloading the tree and initiating failure. The tree risk assessor should be outside the target zone when conducting this type of test.

In a **static pull test**, specially trained assessors attach sensors to the tree to measure marginal fiber strain (stretching and compressing) in the stem

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Dwayne Neustaeter

Figure 2.16 It is important not to pull too hard when performing hand pull tests. Using a throwline limits the force that can be applied to trees and branches being assessed by this method.

or branches, and/or inclination (change in angle) of the root plate in response to a controlled pull (Figure 2.17). The amount of deformation and inclination is compared to reference values to evaluate load-bearing capacity. Working within specific thresholds for tolerable deformations is required to avoid overloading of the tree during the load test. The sensor readings after unloading should confirm that the tree has returned to its original position.

Tree dynamics tests take place under natural wind conditions or with static pulls and are used to measure the movement of an individual tree. Sensors are placed on the trunk and/or near the base to measure fiber strain and/or inclination of the root plate.

Mathematical/Computer Modeling of Loss in Load-Bearing Capacity

The extent of decay affects the load-bearing capacity of a stem. Engineers have developed formulas to predict the loss in load-bearing capacity of pipes, and these formulas can be applied to trees. There are also software packages and apps available to model the loss in load-bearing capacity from measurements of the extent of decay.

There are important limitations that assessors should understand if they use formulas or apps to help assess likelihood of failure.

Limitations include the following:

- Unlike pipes and rods used in structures, tree parts are not perfectly circular. As the tree part's cross section becomes less circular and more irregular, formulas that engineers use for pipes become less applicable to tree parts.
- Similarly, the shape of a hollow area is not perfectly circular; if the hollow area is not surrounded by the same thickness of sound wood around the exterior of the stem, formulas that apply to pipes will be less applicable.

Philip van Wassenaer

Figure 2.17 In a static pull test, sensors are attached to the tree to measure outermost fiber strain in the stem or branches and/or inclination of the root plate in response to a controlled pull. The amount of deformation and/or inclination, measured by sensors, is compared to reference values for that species to evaluate strength or stability. The amount of deformation and/or inclination is very small to avoid damaging the tree.

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- The formulas assume uniform strength properties of a material like concrete or steel, but wood strength can vary throughout the tree.
- The formulas give an estimate of the loss in load-bearing capacity relative to the load-bearing capacity if the stem were not hollow. An assessor should not use the relative loss in load-bearing capacity to compare different trees.
- Assessors should recognize that the **load-bearing capacity** of a large-diameter stem is often much greater than that of a small-diameter stem even if the large-diameter stem is quite hollow.
- The formulas assume that the tree will fail in bending, but that may not always be true.
- Complicating factors such as species, loading, tree size, additional defects, and site conditions must be considered, but there is limited guidance on how they influence the reliability of the formulas.

Other formulas and computer models have been developed to estimate tree stability or loss in load-bearing capacity. Tree risk assessors should recognize that measurements input into formulas or apps are never perfectly accurate or precise. The inaccuracy or imprecision of measurements is known as error or uncertainty. Some formulas rely on multiplication of numbers that an assessor inputs; because of this, the uncertainty is cumulative. As a result, the output of a formula or app could be much less accurate or precise than each individual measurement.

Despite these limitations, and as long as the assessor understands them, mathematical models and calculations can be useful in some advanced tree risk assessments.

Measuring Change of Lean

If the angle of trunk lean continues to increase—that is, it leans more and more over time—the likelihood of failure will also increase because there is a greater bending moment on the root system and trunk. The increase in lean may indicate that the root system or trunk is slowly losing its load-bearing capacity.

E. Thomas Smiley

Figure 2.18 A digital level or other device can be used to monitor even small changes in lean angle. When trunk angle measurements are made over time, it is important to take them at the same location each time. Note the use of pins to ensure the same placement of the level.

Sometimes it is difficult to determine if a tree's lean has changed. A digital level, 3-D stem scans, or an analysis of calibrated images of the trunk can be used to monitor small changes in lean angle. When trunk angle measurements are made over time, it is important that they be taken at the same location each time. However, trunk angle readings taken during the dormant season cannot be directly compared with readings taken when the tree has foliage because the load will be greater when the tree is in leaf. The load will be greater when the tree is covered in precipitation (rain, snow, ice); it will be less during times of drought.

Root Assessment

Root Inspection and Evaluation

The extent of damage or decay in the base of the tree, buttresses, and roots is difficult to evaluate in a basic assessment because most roots are beneath the soil

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E. Thomas Smiley

Figure 2.19 The process of removing materials covering the root collar in order to conduct an assessment is called root collar excavation (RCX). The RCX can be used to locate and examine the main structural roots and to look for decay that could affect stability.

surface and root architecture is not visible. Several types of evaluations can be conducted on roots to assess decay. The simplest is the visual assessment of buttress roots at the basal flares, or where the top surfaces of the roots are exposed, which is typically part of a basic assessment. When not exposed, the tree risk assessor would first need to excavate soil or other materials covering the root collar to conduct the assessment. This process is called **root collar excavation (RCX)**. At a minimum, the RCX should reveal the top of the buttress roots to the point where the root is nearly horizontal or follow roots a distance equal to or greater than the trunk diameter. Depending upon the goal of the assessment, the excavation may need to continue further out along the root. The least injurious method of excavation available should be used. This may involve the use of high-pressure air or water. If necessary, hand tools can be used. Care must be taken not to damage the roots or trunk or destabilize the tree during the excavation process. After excavation, roots can be inspected for evidence of cutting, injury, decay, response growth, or other conditions.

Ground penetrating radar (GPR) may also be helpful to visualize the extent of the root system without needing to excavate it. Use of GPR and interpretation of its output require advanced training.

Root Decay Evaluation

When evaluating root decay, the tree risk assessor should consider that decay in roots often progresses from the bottom of the root upward. Drilling and sonic techniques can help determine the number of roots with decay and the extent of root decay within each root, but they are not designed to quantify the loss in load-bearing capacity of the root system. Tree risk assessors should also consider that drilling into decay in roots can breach CODIT wall 4, which may allow compartmentalized decay to spread. The number of drillings should be as few as possible but as many as needed.

Storm/Wind Load Analysis

Predicting the load on a tree from wind and precipitation is very difficult, even with sophisticated measuring instruments and software. This is due to the challenge of accurately predicting the nature of a storm (such as wind speed and direction, and the amount and type of precipitation), as well as the complicated interaction between trees and wind and precipitation.

Measuring wind speed and direction over time, as well as the amount and type of precipitation, and comparing them to a tree's response as it is loaded can be useful. For example, if an assessor knows that land clearing or some other type of site development will occur in the near future, they can monitor loads and tree response for the months before and after the site changes. With careful analysis, the assessor may be able to detect a change in the tree's response to loads following the removal of nearby trees or the addition of a building.

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Tree Health Evaluation

Quantifying tree health, especially from a historical perspective, can provide helpful information about how well a tree may tolerate changes in growing conditions, site use, or loading patterns as well as how quickly response growth will form. Techniques to evaluate tree health include analyzing growth rings from increment cores (for trees growing in temperate zones) and measuring shoot length. Lab analyses are also useful. They include identifying pests; analyzing foliage to determine nutrient levels, water potential, and chlorophyll fluorescence; and measuring starch levels in xylem.

Information about a tree's health can be used to determine its ability to compensate for loss in load-bearing capacity (by forming response growth), compartmentalize decay, and resist abiotic and biotic factors that cause physiological stress.

Weather Analysis

Weather analyses can be used to measure or estimate prevailing wind direction and speed or the likelihood of extreme storm events in a given area based on the history of such events. A wind rose chart, for example, summarizes the historical record of wind direction and speed. Analyzing historical weather data can be particularly important if an assessor is working in an unfamiliar region. Weather analyses can better inform an assessor of the expected frequency of severe loading from wind, snow, ice, or heavy rain.

E. Thomas Smiley

Figure 2.20 When evaluating root decay, keep in mind that decay in roots may be centralized but sometimes progresses from the bottom of the root upward.

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Summary

Three levels of assessment have been defined and should be included in the scope of work:

- A Level 1 limited visual assessment involves a visual assessment of an individual tree or a population of trees near specified targets, conducted from a specified perspective to identify specified conditions or obvious defects.
- A Level 2 basic assessment is the typical assessment performed in response to a tree owner's request for tree risk assessment. It consists of a tree and its surrounding site from the ground and a synthesis of the information collected.
- A level 3 advanced assessment is performed to provide detailed information about specific tree parts, defects, targets, or site conditions. Advanced assessments can provide additional information that may make the difference between recommending tree retention or removal.

Key Concepts

1. Level 1 limited visual assessments are the fastest but least thorough means of assessment and are intended primarily for managing large populations of trees when time and resources are limited.
2. A Level 2 basic assessment requires that an assessor look completely around the tree to perform a detailed visual assessment of the site, buttress roots, trunk, and branches.
3. Assessment of populations of trees may employ a Level 1 assessment to determine which trees should receive a Level 2 or Level 3 assessment.
4. Because specialized equipment, data collection and analysis, and/or expertise are usually required for Level 3 advanced assessments, they are generally more time-consuming and expensive than basic assessments. Procedures and methodologies should be selected and applied as appropriate; what is reasonable and proportionate to the specific conditions and situations should be considered, and tree damage should be minimized.

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Target Assessment and Tree Risk Factors

Module 3

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Target Assessment

Module 3

Learning Objectives

- Explain the rating categories for likelihood of failure, likelihood of impacting a target, and consequences of failure.
- Explain what a target is in tree risk assessment and give examples of types of targets.
- Discuss how targets are considered when estimating both the likelihood of impact and the consequences of failure in risk categorization.
- Describe how a target zone is determined and explain why an individual tree may have multiple targets.
- Compare and contrast different types of targets, including how each affects occupancy rates.
- Discuss how to assess target occupancy rates and their effects on the likelihood of impact.
- Explain the factors to be considered when categorizing likelihood of impact and the consequences of failure.
- Explain the reason and process used for stratifying and prioritizing targets.

Key Terms

consequences of failure
direction of fall
disruption
known target
likelihood of failure
likelihood of impact
mobile target
movable target
occupancy rate
prioritizing
protection factors
static target
stratifying
target
target aggregation
target zone
time frame

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Introduction

This module covers two important concepts: target assessment and the three tree risk assessment factors that determine the risk rating. These concepts are interrelated because target characteristics are integral to categorizing the factors that determine tree risk.

A primary goal of tree risk assessment is to provide information about tree risk—specifically, the level of risk posed by a tree over a specified **time frame**. In qualitative tree risk assessment, this is accomplished by categorizing the likelihood and consequences of an event. These factors are determined by categorizing the following:

a) the likelihood of failure of a tree within the specified time frame

b) the likelihood that a failed tree could strike a person(s) or property, or could disrupt activities, within the specified time frame

c) the consequences of the failed tree impacting the target

In tree risk assessment, targets (risk targets) are people who could be injured, property that could be damaged, or activities that could be disrupted by a tree failure. Targets include people, buildings, animals, power lines, infrastructure, vehicles, landscape features, and other property.

Risk assessment is undertaken where there are one or more targets of concern that could be impacted by one or more trees, and the tree risk manager

Definitions of Some Key Terms

Several key terms are required to understand and assess targets and tree risk factors. Below is a partial list of terms. A more comprehensive list can be found in the Glossary of Terms.

consequences of failure—personal injury, property damage, or **disruption** of activities due to the failure of a tree. Categories are *severe*, *significant*, *minor*, and *negligible*.

known target—target(s) that are visible to the tree risk assessor, and those described by the tree risk manager.

likelihood of failure—the chance of a tree failure occurring within the specified time frame. Categories are *imminent, probable*, *possible*, and *improbable*.

likelihood of impact—the chance that if the tree fails during the specified time frame, it will impact a target. Categories are *high*, *medium*, *low*, and *very low*.

occupancy rate—amount of time the target is within the target zone during the risk assessment time frame. Categories are *constant*, *frequent*, *occasional*, or *rare*.

protection factors—features such as structures, trees, or vehicles that would block, deflect, or slow down a falling object.

target (risk target)—people that could be injured, property that could be damaged, or activities that could be disrupted by a tree failure.

target aggregation—combining two or more targets when rating the likelihood of impact.

target zone—the area where a tree is likely to land if it fails; the size and shape can vary by tree failure type.

time frame—the period for which an assessment is defined.

tree failure—the breakage of stems, branches, or roots, or the loss of mechanical support in the soil-root system. Unless specifically stated otherwise, in this Manual, "tree failure" means failure of the whole tree, branch, or other parts.

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thinks that target value or the possible consequences of tree failure justifies the expense of conducting the assessment. Sometimes, risk assessment is required by law. Evaluating potential targets is one of the first steps in the risk assessment process.

Evaluating Potential Targets

Target assessment is an important step toward arriving at a tree risk assessment. Both the likelihood that a failed tree could strike a person(s) or property or disrupt activities within the specified time frame, and the consequences of the failed tree impacting the target are dependent on the nature of the target.

What is a Target?

Targets are people who could be injured, property that could be damaged, or activities that could be disrupted by a tree failure. Targets include people, buildings, animals, power lines, infrastructure, vehicles, landscape features, and other property.

Because people are the most valuable target, tree risk managers should prioritize locations where people are commonly present. Examples include areas near large trees such as homes, streets, parking areas, footpaths, picnic areas, campgrounds, play areas, bus stops, and city centers. This is especially important in areas where people may congregate under trees during storms.

E. Thomas Smiley

Figure 3.2 Streets, sidewalks, and trails are rarely considered targets. It is the vehicles on streets that could be damaged, traffic on streets that could be disrupted, or people who could be injured that are the more important targets to consider.

Bryan Kotwica

Figure 3.1 Targets are people, property, or activities that could be injured, damaged, or disrupted by a tree failure. If this large tree were to fail at the root system, targets would include the pedestrians, food vendors, traffic, parked cars, utility lines, and the house.

Structures represent another large group of potential targets. They include houses, garages, outbuildings, commercial buildings, picnic shelters, statues, and monuments. Although damage to structures and infrastructure occurs, the greater concern is for people, even if people are not present at the time of the assessment.

Roadways are a commonly assessed target area. Targets include vehicles and people traveling in them, bicyclists, and pedestrians on a sidewalk adjacent to the road. In addition, the assessor can consider the flow of traffic on a roadway that would be obstructed by a tree falling across the road, even if a vehicle is not struck. Tree failures may also result in

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an accident—for example, if a car swerves to avoid a fallen tree and collides with another vehicle or pedestrian—even if the failed tree does not impact the vehicle or pedestrian.

Normally an assessor does not identify the sidewalk or road as a target but considers the people who use the sidewalk or road. When assessing the risk of a tree failing into a parking area, the assessor may consider cars, people inside the cars, and people walking to and from cars.

Power lines and utility facilities are targets of great importance to electrical utility providers and their customers. The lines and infrastructure have inherent value, and the disruption of electricity has consequences.

Identification of targets is the joint responsibility of the tree risk manager and the tree risk assessor. Assessors should discuss potential targets and their value with the tree risk manager. Sometimes targets are not present at the time of the tree risk assessment or may not be apparent to the tree risk assessor.

Multiple targets are present at most sites. For instance, the possible consequences of a tree falling across a road include:

- Injury to people in a vehicle or on the road
- Damage to a moving or stationary vehicle
- A moving vehicle running into the tree that has just failed
- Crashed vehicle after suddenly stopping or swerving to avoid the fallen tree
- Blocked access to locations farther along the road
- Disruption of utility services
- Costs and inconvenience factors associated with clean-up and remediation

Targets of particular concern to electrical utility risk managers are electric lines and facilities. Lines brought down by a falling tree are a threat to people who may make contact with them, and there may be a risk of fire. There are also costs, inconvenience, and possible losses associated with the disruption of service that will potentially impact many people. Trees that fall on utilities can pose a serious risk of disruption in addition to the risk of killing or injuring people or damaging property. Electric transmission lines and distribution lines that service large populations should be considered of greater importance than minor distribution lines.

A **known target** is one that is visible to the tree risk assessor, and those described by the tree risk manager. For this reason, it is best to evaluate the targets in consultation with the tree risk manager so that site uses can be discussed and targets that may not be present during the assessment may be included.

The scope of work may include a list of targets. The tree risk manager can limit target consideration to a few high-value targets (e.g., people, houses, power lines). The risk manager should also direct the assessor to consider targets individually (e.g., a single house that the falling tree could strike) or in aggregate (e.g., any house that the falling tree could strike).

Target Zone

The **target zone** is the area where the tree is likely to land if it fails. The target zone can vary by failure type. For example, the target zone may be much larger if considering whole-tree failure than it would be for failure of a single branch. To determine the

Common Targets That Are Often Considered in Tree Risk Assessments:

- People
- Buildings
- Vehicles
- Electric utility lines and facilities
- Pets, livestock
- Transportation corridor
- Landscape features (e.g., lights, irrigation systems, benches, sculptures, furniture, specimen plants)

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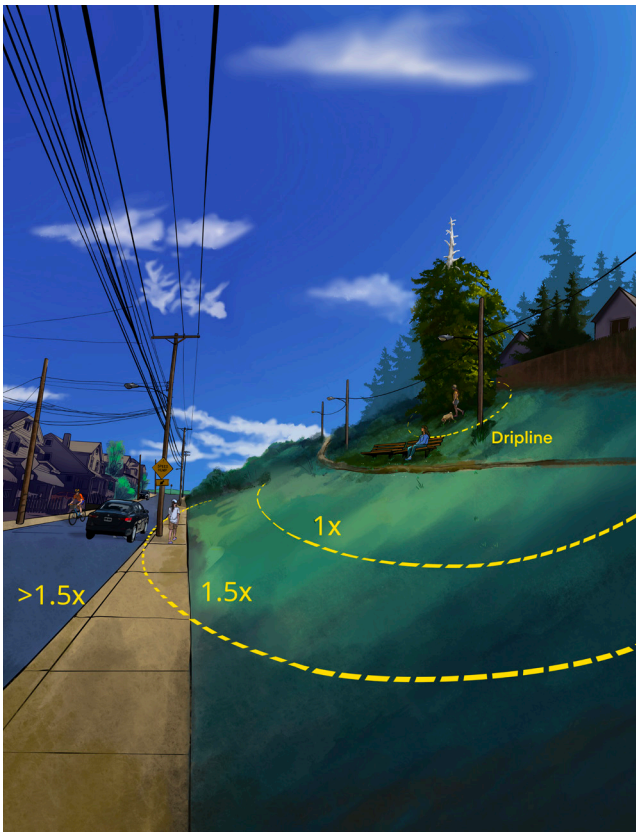
target zone, the assessor considers the likely direction of fall, height of the tree, crown spread, topography, wind, and potential for wood fragments to travel upon impact.

For whole-tree failure, the target zone is often a circle around the tree with a radius equal to about 1 to 1.5 times the height of the tree. The radius may change depending on whether the tree is dead. The target zone for dead trees is generally larger because dead wood is more likely to shatter upon impact, spreading debris some distance beyond the tree (Figure 3.3). Leaning trees, trees on slopes, and trees with asymmetric crowns may have irregularly shaped target zones rather than circular ones.

E. Thomas Smiley

Figure 3.4 Static or unmovable targets include permanent or semipermanent (not easily moved) structures such as buildings and power lines.



Casey Jones

Figure 3.3 The target zone is the area where a tree or branch is likely to land if it were to fail. Due to the brittle dead branches at the top of this tree, the target zone radius may extend 1.5 times the tree height or further.

For lower-branch failure, the target zone is usually limited to the area below the branch. As with the target zone for dead trees, the target zone for a dead branch may increase to account for intermediate branches, and the shattering and spreading of debris.

The size of the target zone may increase if one tree could fall into another and cause it to fail. Conversely, the target zone may decrease in size depending on the direction of trunk lean.

The direction of fall can affect the target zone but is often difficult to predict. Assessors should consider factors that may influence the direction of fall. The direction of loading and the location of defects that reduce load-bearing capacity can influence the size and location of the target zone.

On steep slopes, whole trees may continue moving even after they land on the ground. This may extend the target zone beyond 1.5 times the tree height.

Categorization of Targets

Targets can be categorized by whether they can move or be moved.

- A **static target** is fixed or not easily moved. Examples include buildings, utility facilities, fences, and light fixtures.

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- A **movable target** can be relocated. Examples include sculptures, picnic tables, and parked cars.
- A **mobile target** is one that is in motion or intermittently moving. Examples include people, animals, and vehicles.

Static Targets

Static or unmovable targets include permanent or semipermanent (not easily moved) structures such as buildings, mobile homes/offices that are on a foundation (no longer on wheels), and power lines. They also include features such as park benches that are permanently fixed to the ground and cannot be easily moved.

Luana Vargas

Figure 3.5 Movable targets can move or be moved relatively easily. They may be relocated beyond the target zone; however, movable targets might later be moved back into the target zone if not affixed to the ground.

Movable Targets

Movable targets are not fixed in a location and can be moved. Examples include parked cars, camper vans, mobile offices that are on wheels, benches, picnic tables, and portable toilets. However, if it is possible that the movable target will later be moved back into the target zone, it may be reasonable to rate them at a higher level until the risk manager can ensure they have been permanently relocated. For example, people may move picnic tables under trees so that they will be in the shade and thus could expose themselves to greater risk without realizing it.

Mobile Targets

Mobile targets are those that move continuously or intermittently. People move through target zones as pedestrians, cyclists, or as occupants in a vehicle. Because mobile targets move at different speeds and sometimes stop for varying periods of time, assessment of mobile targets should consider the amount of time they are within the target zone (the **occupancy rate**).

E. Thomas Smiley

Jim Clark

Figure 3.6 Mobile targets are those that are moving continuously or intermittently.

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Time Frame and Target Zone Occupancy

Time frame is the period for which an assessment is defined. The time frame is the specified length of time for which the assessor is considering the likelihood of failure and impact. Specifying the time frame is discussed later in this Module.

Target zone occupancy varies over time. For example, streets are busier during morning and evening rush hours, city center areas are busier during the day, parks are busier during the weekends, campgrounds are busier during the summer, and event sites are only occupied during an event. Typically, the time frame includes both busy and less occupied times throughout the year.

In some cases, the tree risk manager may only be concerned about trees during times of highest occupancy. This may be the case with campgrounds and event sites. To assess risk during periods of high occupancy, the risk manager may specify a short time frame such as during the week of an event (e.g., fair, concert) or season of high activity (e.g., summer season at a park or campground). Specifying a short time frame to correspond to high occupancy rates is an acceptable practice.

Different time frames may also be used for portions of large tree populations, such as within a city. The tree risk manager may specify that a city park be assessed for a three-year time frame while center city areas may be given a one-year time frame.

Target Zone Occupancy (Occupancy Rate)

Targets are categorized based on the amount of time the target is within the target zone during the defined assessment time frame: the "occupancy rate." Occupancy rate is the primary component in determining the likelihood of impact.

Occupancy can be categorized as follows:

● ***Constant***—*Constant* occupancy indicates the target is always or nearly always present.

Examples* of *constant* occupancy may include:

- Structures such as houses, buildings, powerlines, fences, light fixtures, sculptures, landscape plantings, and other features.
- People in areas that are nearly always occupied (city centers in cities that "never sleep").
- People in an event site during times in which the event is scheduled (the time frame is the event period).
- Vehicles parked in long-term parking lots, high-use overnight parking spaces, and automotive sales lots.
- Vehicles traveling in a continuous flow on streets, roads, or highways nearly all times of the day and night.
- Recreational vehicles in busy campgrounds when the time frame is the camping season.

● ***Frequent***—*Frequent* occupancy indicates the target is present much of the time.

Examples* of *frequent* occupancy may include:

- People in busy areas such as city centers, transit hubs, and shopping areas.
- Vehicles that are parked in the target zone most of the day or night.
- Vehicles traveling on busy streets, roads, or highways.
- People in busy campgrounds when the time frame is the camping season.

● ***Occasional***—*Occasional* occupancy indicates the target is present intermittently.

Examples* of *occasional* occupancy may include:

- People using residential sidewalks or foot paths near schools or shopping areas.
- People using public garden trails.
- People in picnic areas or seasonal campgrounds within a one-year time frame.

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- Vehicles parked during the day on lightly used residential streets.
- Vehicles moving on streets with moderate traffic.

● ***Rare***—*Rare* occupancy indicates the target is not commonly in the target zone.

Examples* of *rare* occupancy may include:

- People walking to a parked car, garage, or storage building.
- People mowing their lawn.
- People on lightly used residential sidewalks, hiking trails, or foot paths.
- People in forest areas
- Vehicles parked for deliveries or traveling on lightly used residential streets.

*These examples are provided to assist tree risk assessors with categorizing target zone occupancy rates. Tree risk assessors should consider anticipated weather conditions at the time of failure, use patterns, and other factors that may affect occupancy.

E. Thomas Smiley

Figure 3.7 *Constant* occupancy. *Constant* occupancy indicates that a target is present at nearly all times, 24 hours a day, 7 days a week, 365 days a year. Examples include static, unmovable targets such as buildings or power lines.

E. Thomas Smiley

Figure 3.9 *Occasional* occupancy. *Occasional* occupancy describes target zones that are occupied by people or targets intermittently. Examples include people on residential sidewalks and vehicles moving on streets with moderate traffic.

E. Thomas Smiley

Figure 3.8 *Frequent* occupancy. *Frequent* occupancy indicates that the target zone is occupied most of the time. Examples include people in busy areas such as city centers and transit hubs; vehicles that are parked in the target zone most of the day or night; and vehicles traveling on busy streets, roads, or highways.

Doug Sharp

Figure 3.10 *Rare* occupancy. *Rare* occupancy indicates that the target zone is not commonly occupied. Examples include people walking to parked cars; people mowing their lawn; and vehicles parked for deliveries or traveling on lightly used residential streets.

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Static targets have *constant* occupancy if they are within the target zone. Movable and mobile targets can be categorized in any of the four occupancy classifications.

Occupancy rate can vary considerably with season, time of day, day of week, weather, etc. The tree risk assessor's perception of occupancy rates can be affected by the timing of the visit and the length of time spent performing the assessment.

The tree risk manager may provide information about occupancy. The tree risk assessor will categorize occupancy based on that information and their observations. Occupancy can be assessed by observing the presence of targets as well as signs of use in features such as foot paths, sidewalks, pavements, play areas, and picnic tables.

While occupancy is the primary factor in categorizing the likelihood of impact, it is not the only factor. A target categorized as having *constant* occupancy does not mean that it will necessarily be impacted by a tree failure. **Direction of fall** (in relation to the location of the target in the target zone), **protection factors**, and location within the target zone can all affect the likelihood of impact.

Occupancy Rates of Mobile Targets

Mobile targets can be difficult to assess because the amount of time spent in the target zone can vary. For example, pedestrian traffic along a city street may be *occasional* or *rare* during night hours but *frequent* during business hours.

The exposure time of mobile targets in the target zone depends on factors such as how fast the target is moving, whether a target is likely to be stationary for a period of time within the target zone, and the size of the target zone. For example, if vehicles or people move past the tree on a trail or road, they spend only a short time in the target zone. At a typical walking pace of 3 mph (5 kph), the exposure time is approximately 5 to 10 seconds, depending on the size of the target zone. If, however, a pedestrian stops to wait for a traffic light or read a sign, the exposure time will be longer. The tree risk assessor should consider factors that could affect the amount of time the mobile target is within the target zone.

A passing car has less exposure time than a pedestrian because it moves at greater speed. If many people or vehicles are passing by the tree, then the cumulative exposure time and the occupancy rate will be higher. For mobile targets, assessors should consider that occupancy rates are often significantly lower during nighttime hours. The days of the week and seasons of the year can also affect occupancy rates, so assessors must account for these differences when categorizing the occupancy rate for the time frame. In some cases, more detailed information may be needed about the frequency of occupancy within the target zone than can be observed during a basic assessment. For instance, it may be possible to obtain traffic data and use patterns by time of day or season and to assign occupancy rates based on known use patterns. Investigating frequency of occupancy and analyzing data is an advanced assessment (Level 3) that would only be undertaken if the work is proportionate to the potential consequences, and it was included in the scope of work.

Weather conditions may influence occupancy rates. Most tree failures occur during adverse weather events. In general, it is reasonable to assume that there will be fewer people occupying a park, or on a trail during storms. However, in center cities or business areas, the pedestrian occupancy rates may not change. Moreover, vehicle traffic may increase in rainy weather when people typically avoid being outside and exposed to the weather.

Tree Risk Assessment Factors

In this section, the three tree risk assessment factors that determine the risk rating are introduced. The information presented here will be built upon in subsequent modules.

Tree risk assessment provides information about the level of risk posed by a tree over a specified time frame. This is accomplished in qualitative tree risk assessment by categorizing the likelihood of failure and impact, and then categorizing the consequences of a tree failure (Figure 3.11). Assessing the likelihood of impact and the **consequences of failure** are discussed below. Assessing the likelihood of failure is

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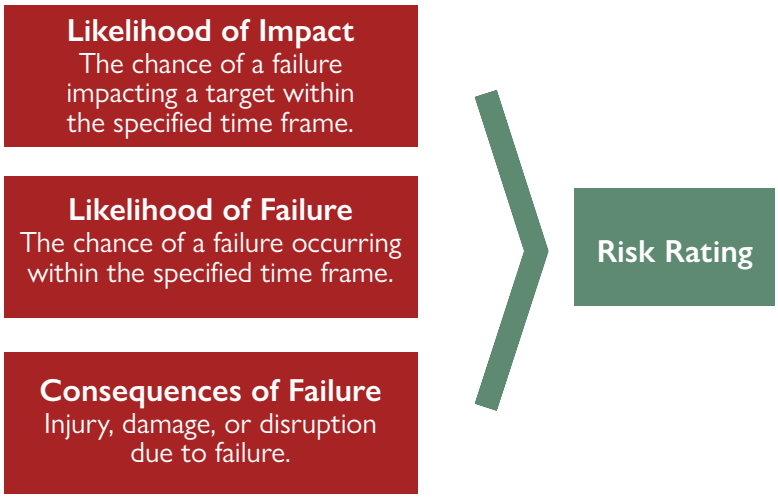

Figure 3.11 Three factors are assessed to determine the risk rating.

discussed in Modules 4 and 5, as well as more fully in Module 6.

Specifying the Time Frame

The time frame is the specified length of time for which the assessor is considering the likelihood of failure and impact. Without a specified time frame, the likelihood of failure rating is meaningless. The time frame is usually decided with or specified by the tree risk manager and is included in the scope of work.

Tree and site conditions change over time. The likelihood of failure may increase due to advancing decay or decrease due to response growth. In addition, the longer the time frame the more likely severe weather will occur within the time frame.

Assessments may be conducted using more than one time frame. For example, an assessment can be done for the next one year as well as for the next three years. In some cases, the results will be different. Sometimes, having assessments consider more than one time frame can be helpful for the tree risk manager in making mitigation choices. The longer the time frame, the greater the uncertainty.

Time frames of one or three years are commonly used in tree risk assessments. These time frames are typically appropriate for suburban properties, moderately well-used parks, street trees, and many business areas.

Time frames shorter than one year may be used in areas of *constant* or *frequent* pedestrian occupancy such as in center city business districts with large, mature trees. Longer time frames (5 years or more) could be considered where targets are *infrequent* or *rare*, and the consequences of failure would be *low*.

Likelihood of Impact

The **likelihood of impact** is the chance that if the tree fails, it will strike a target during the specified time frame. The occupancy rate is the primary factor for determining the likelihood of impact, but two other considerations are target protection factors and the direction of fall.

Target Protection Factors

Protection factors are structures, trees, or other features that may block, deflect, or slow down a falling tree. The presence of one or more of these factors can reduce the likelihood of impact and the consequences of failure and impact. When considering a tree striking a person, common protection factors include vehicles, houses, and other structures. Trees or branches located between the tree being assessed and a target may serve as protection factors. Large adjacent trees or lower branches may stop the fall of another tree or branch.

Conversely, multiplicative factors are conditions that may increase the target zone and likelihood of impact. For example, sequential whole tree failures may occur on sites with recently exposed trees that are not adapted to the new environmental conditions. This is more likely when a large tree falls into a smaller tree.

Direction of Fall

Another important consideration when categorizing the likelihood of impact is the direction that a tree or branch could fall and the location of the target in the target zone. A target can be in the target

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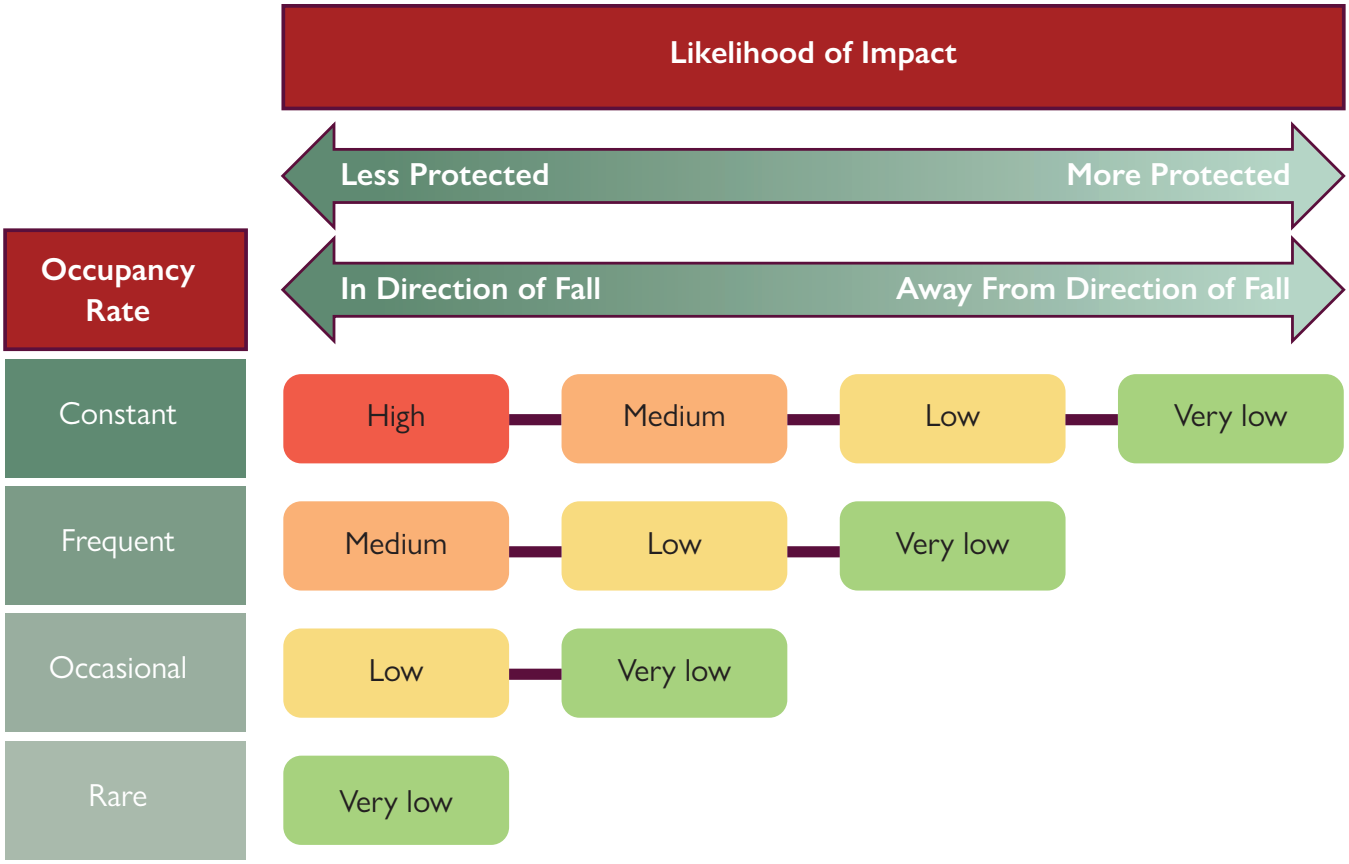

Figure 3.12 Occupancy rate is the primary determining factor for likelihood of impact. As occupancy rate decreases from *constant* to *rare*, likelihood of impact also decreases. The expected direction of fall and protection factors can also affect likelihood of impact.

zone, but the tree or tree part may not be likely to fall in the direction of the target.

Categorizing the Likelihood of Impact

The likelihood of impact is categorized as: *high*, *medium*, *low*, or *very low*:

● ***High***—*High* likelihood of impact indicates the failed tree is likely to impact the target (Figure 3.14). This applies when there is *constant* occupancy within the target zone, no protection, and the direction of fall is toward the target.

Examples* of *high* likelihood of impact may include:

- A tree leaning directly toward a building: the building is a static target and has *constant* occupancy; the lean influences the direction of fall toward the building; nothing will prevent the leaning tree from impacting the building if it falls in the direction of the lean.
- A tree leaning directly over a road with a continuous flow of traffic: traffic is mobile, but the continuous flow gives it *constant* occupancy; the lean influences the direction of fall toward the road; nothing will prevent the leaning tree from impacting a passing vehicle if it falls in the direction of the lean.
- A branch directly over a building without any protection factors: the building is a static target and has *constant* occupancy; the branch will fall directly toward the building below it; nothing will prevent the branch from impacting the building if it falls.
- A tree surrounded by structures within the target zone: the structures are static targets

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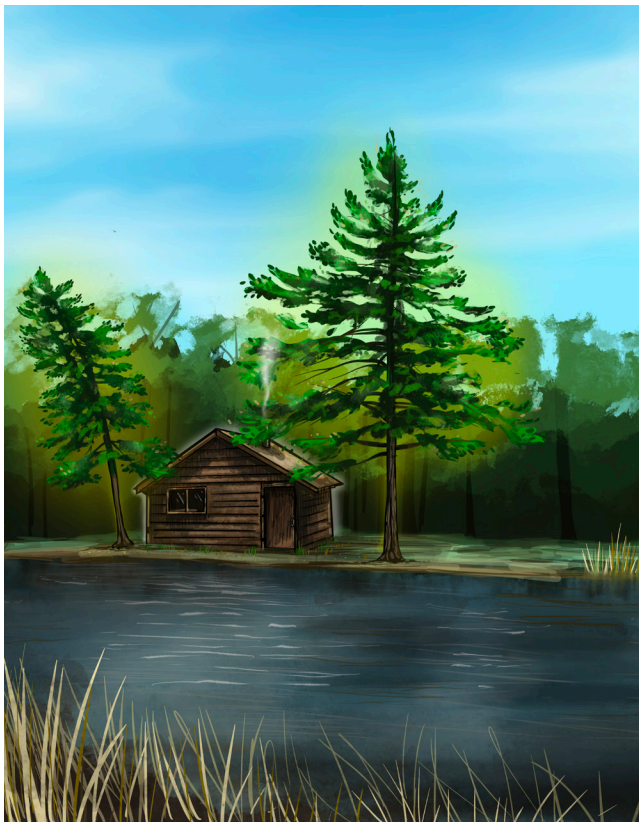
and have *constant* occupancy; the lack of a lean is not relevant because there are structures surrounding the tree; nothing will prevent the tree from impacting a structure if it falls.

Medium—*Medium* likelihood of impact indicates the failed tree could impact the target but is not expected to do so (Figure 3.15). This applies when mobile targets are *frequently* within the target zone and the direction of fall is toward the target; when the direction of fall may or may not be toward a static target within the target zone; or when a static target has *constant* occupancy and may be protected from the falling tree.

Examples* of *medium* likelihood of impact may include:

- A branch high in a tree with lower branches between it and a building below: the building is a static target (and has *constant* occupancy); the branch will fall directly toward the building; lower branches may prevent the branch from impacting the building.
- Branch over an arterial street with regular traffic flow: the street does not experience a continuous flow of traffic, so the occupancy rate is *frequent*; the branch will fall directly toward the street; nothing will prevent the branch from impacting a passing vehicle.
- A tree with no lean immediately adjacent to a street with continuous traffic flow: traffic is mobile, but the continuous flow gives it *constant* occupancy; nothing will prevent the tree from impacting a passing vehicle if it falls in the direction of the street; since the tree is not leaning, the fall direction is difficult to predict.



Casey Jones

Figure 3.13 Likelihood of impacting a target depends on target zone occupancy rates, direction of fall, and any protection factors. Here, the likelihood of the tree leaning over the water (left) falling on the cabin is *very low,* and the likelihood of the other tree (right) falling on the cabin is *medium*.

Low—*Low* likelihood of impact indicates there is a slight chance that if the tree were to fail it will impact the target (Figure 3.16). This applies when mobile targets are *occasionally* in the target zone; when the expected direction of fall is not toward the target; or when a *constant* target is protected from the falling tree.

Examples* of *low* likelihood of impact may include:

- A branch in close proximity to, but not directly over, a building: the building is a static target and has *constant* occupancy; nothing will prevent the branch from impacting the building; the branch will fall but not directly toward the building.
- A tree leaning toward an arterial street with a larger tree between it and the street: the street does not experience a continuous flow of traffic, so the occupancy rate is *frequent*; the lean will influence the direction of fall toward the street; the larger tree will dramatically reduce the chances that the smaller tree would impact a passing vehicle.
- A tree next to a sidewalk sometimes used by pedestrians: the flow of pedestrians is intermittent, so the occupancy rate is *occasional*; the tree has a slight lean toward

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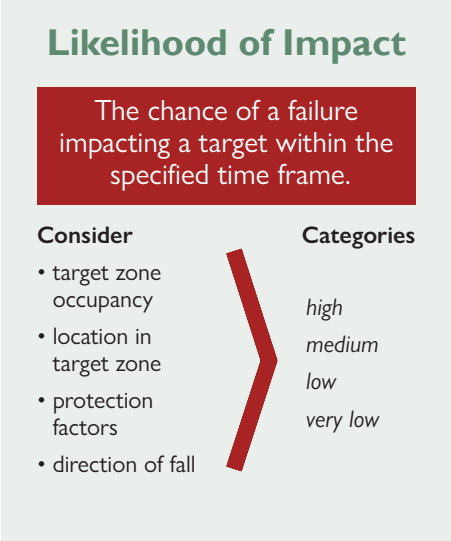
the sidewalk; nothing will prevent the tree from impacting a passing pedestrian.

- A tree leaning towards an apartment building: considering people inside the building as the target rather than the building itself, the occupancy rate is *frequent*; the lean will influence the direction of fall; the building will reduce the chance that the tree will impact a person inside.



Very low—*Very low* likelihood of impact indicates the chance of the failed tree impacting the specified target is remote (Figure 3.17). Likelihood of impact could be *very low* if the target zone occupancy is *rare*; the tree is likely to fall in the opposite direction of the target; the occupancy rate is *occasional* and the tree may or may not fall toward the target; occupancy is *frequent* and the tree is likely to fall in a different direction; or the occupancy rate is *constant* and the tree would fall in a different direction or the target is well-protected.

Examples* of *very low* likelihood of impact may include:

- A tree near a hiking trail, foot path, or sidewalk that very few pedestrians use: the occupancy rate is *rare* because of low use even if no protection factors are present and the fall direction is toward the pedestrians.
- A tree next to a sidewalk sometimes used by pedestrians with a larger tree between it and the sidewalk: the flow of pedestrians is intermittent so the occupancy rate is *occasional*; the tree is not leaning, so the direction of fall is impossible to predict; the larger tree will reduce the chance that the smaller tree will impact a pedestrian.
- A branch directly over a bus stop that is covered by a sturdy roof: considering a person as the target rather than the roof, the occupancy rate is *frequent*; the branch will fall directly toward the bus stop; the roof will dramatically reduce the chance that the branch will impact a person under the roof.
- A tree leaning away from an historic statue: the statue is static and has a *constant* occupancy rate; nothing will prevent the tree from impacting the statue; the lean will influence the direction of fall away from the statue.

*These examples are provided to assist tree risk assessors with categorizing the likelihood of impact. Tree risk assessors should consider the occupancy rate within the time frame, expected direction of fall (in relation to the target location within the target zone), and protection factors that could affect the categorization.

Target Aggregation

Targets are usually assessed on an individual basis, but they can also be combined to provide the tree risk manager with a better perspective of what could happen if a tree fails. For example, a straight tree, with considerable root decay, is located in a courtyard surrounded on three sides by a house, a garage, and a workshop. The house can be considered as an individual target with a *medium* likelihood of impact. Alternatively, all three targets can be considered in combination (in aggregate) as "structures." In that case, the likelihood of impact would be *high*, since the structures surround the tree on three sides and, if the tree were to fail, it would probably impact one of the structures. These examples demonstrate the need to clearly define the targets and what risk is being rated. In this case, the risk being considered is either "the house" or "structures."

Likelihood of Failure

A tree failure is the breakage of stems, branches, or roots, or the loss of mechanical support in the soil-root system. The **likelihood of failure** is the chance of a tree failure occurring within the specified time

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Figure 3.14 *High* likelihood of impact. The failed tree or tree part is likely to impact the target. The likelihood of a branch failure from this tree impacting a vehicle below is *high* because the tree is near an intersection of two busy streets.

Luana Vargas

Figure 3.15 *Medium* likelihood of impact. The failed tree or tree part could impact the target but is not expected to do so. The likelihood of a branch impacting a parked vehicle on this street is *medium* because the occupancy rate is *frequent*.

Nelda Matheny

Figure 3.16 *Low* likelihood of impact. There is a slight chance that the failed tree or tree part could impact the target. The likelihood of this tree impacting a vehicle or pedestrian is *low* because the rural road shows limited use, and the fall direction may not be toward the road.

E. Thomas Smiley

Figure 3.17 *Very low* likelihood of impact. The chance of the failed tree impacting a specified target is remote. The likelihood of the branch impacting the person is *very low* because people are rarely present along the shoulder of this rural, low-use road.

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CASE STUDY

Occupancy Rate and Likelihood of Impact

Assignment: The tree risk assessor was called to assess the risk of the black locust (*Robinia pseudoacacia*). The client is considering converting the building near the tree to a child daycare facility. Part of the decision-making process is deciding if the tree poses too much risk to the children and adults that would be present at daycare. The client wants the risk assessed with the daycare facility. Due to the importance of the targets and the potential for changing conditions, the client (risk manager) decided upon a one-year time frame.

Time Frame: One year

Targets and Site: The building is unlikely to be impacted due to the anticipated direction of fall. If the building is converted to a daycare facility, a play area will be established on the left side of the tree that extends from the dripline to the base of the tree. Because groups of children will use the area throughout the entire day (12 hours), including Saturdays, the occupancy rate for people in the play area will be *frequent*. There are no protection factors, and the direction of fall is toward the future play area. The likelihood of impacting a person is *medium*.

Tree Conditions: The tree has two stems that split apart nearly to the base many years ago. There was some response growth on both sides of the crack and at the base. Both trunks have visible decay. The likelihood of stem failure at ground level due to decay was rated as *probable* within the one-year time frame.

Analysis: The likelihood of stem failure is *probable*. The building would not be impacted if the tree were to fail so the likelihood of impact is *very low*, making the likelihood of failure and impact *unlikely* (Matrix 1). The consequences are *significant*. When these categories are combined using Matrix 2, the risk rating is *low*.

The likelihood of impact is *medium* for people using the site, the target of greatest concern. The likelihood of failure (*probable*) and the likelihood of impact (*medium*) are combined using Matrix 1, yielding a rating of *somewhat likely*. The consequences of failure (impacting a person) is rated as *severe*. With a likelihood of failure and impact category of *somewhat likely* and *severe* consequences of the failure, the risk is rated as *moderate*.

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Mitigation Options: Several options were presented to the client:

1. Remove dead and dying branches, reduce the crown by 20 percent over the proposed play area, and cable and brace the two stems together to reduce likelihood of failure.
2. Build the play area in another location and outside the target zone; block access to the area within the target zone.
3. Remove the tree.
4. Do nothing and accept the risk.

The client had a *low* threshold for risk. Even though the first two mitigation options would reduce the residual risk to *low*, they would not eliminate the risk. Given the nature of the targets, the client opted to remove the tree.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photos by Julian A. Dunster

frame. The rating for likelihood of failure will later be combined with the likelihood of impact to determine the likelihood of failure and impact.

Many factors are considered when categorizing the likelihood of failure. These include site and weather conditions, tree health, loads, tree defects and other conditions that can reduce load-bearing capacity, and growth adaptations that can increase load-bearing capacity. These factors are explored in more depth in Modules 4, 5, and 6.

Categorizing the Likelihood of Failure

The tree risk assessor needs to categorize the likelihood of failure for any tree for which they are developing a risk rating. Following are definitions for likelihood of failure and examples to assist tree risk assessors in categorizing the likelihood of failure. A three-year time frame is used in these examples, but tree risk assessors and managers should select a time frame that is appropriate for the situation.

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The likelihood of failure is categorized as follows:

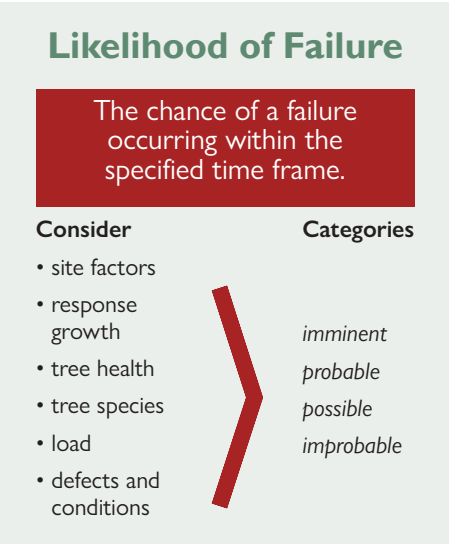
● ***Imminent***—*Imminent* likelihood of failure indicates that failure has begun or will occur soon in normal weather or with minimal additional loading (Figure 3.18). If a tree risk assessor identifies a tree with an *imminent* likelihood of failure, they should consider alerting the tree risk manager.

Tree risk assessors rarely encounter trees with an *imminent* likelihood of failure. The *imminent* category supersedes the specified time frame.

Examples* of *imminent* likelihood of failure may include:

- Recently broken hanging branch that is not well-supported by other branches.
- Dead tree or branch with extensive decay at the base.
- Codominant stem with a crack below the union that opens and closes as the tree moves in the wind.
- Transverse (horizontal) crack that goes into the wood of the trunk.
- Visually apparent soil lifting in response to trunk and root movement.

● ***Probable***—*Probable* likelihood of failure indicates indicates that failure may occur in normal weather and is expected to occur in severe weather within the specified time frame (Figure 3.19).



Examples* of *probable* likelihood of failure within the next three years may include:

- Broken hanging branch that is lodged in other branches.
- Some dead branches.
- Weakly attached or overextended horizontal branch with multiple, heavy adventitious sprouts.
- Codominant stem with significant heartwood decay within or below the union.
- Tall, exposed tree with low live crown ratio and extensive heartwood decay in the lower trunk.
- Exposed tree with all structural roots on one side of the tree cut or decayed.

● ***Possible***—*Possible* likelihood of failure indicates that the failure is not likely in normal weather but may occur in severe weather within the specified time frame (Figure 3.20).

Examples* of *possible* likelihood of failure within the next three years may include:

- Declining branch that is likely to die.
- Overextended branch on species prone to dropping live branches.
- Codominant stem with included bark and narrow attachment.
- Tree with a moderate amount of heartwood decay in the lower trunk.
- Trunk with a seam and heartwood decay.
- Tree with a few cuts or decayed structural roots.

● ***Improbable***—*Improbable* likelihood of failure indicates that failure is not likely in normal or severe weather within the specified time frame (Figure 3.21).

Examples* of *improbable* likelihood of failure within the next three years may include:

- Healthy branches with good taper and weight distribution.

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Figure 3.18 *Imminent* likelihood of failure. The likelihood of failure of this tree is *imminent* due to the open and active crack in the trunk. Failure has started or is most likely to occur in the near future, even if there is no significant wind or increased load.

E. Thomas Smiley

Figure 3.19 *Probable* likelihood of failure. These conks indicate the presence of root decay, making the likelihood of failure *probable* within a three-year time frame. Failure may be expected under normal weather conditions within the specified time frame.

E. Thomas Smiley

Figure 3.20 *Possible* likelihood of failure. The codominant union shows significant response growth, indicating a *possible* likelihood of failure within a three-year time frame. Failure may be expected in severe weather conditions, but it is unlikely during normal weather conditions within the specified time frame.

E. Thomas Smiley

Figure 3.21 *Improbable* likelihood of failure. This seam from frost cracking has not resulted in internal decay and is an example of *improbable* likelihood of failure within a three-year time frame. The tree or tree part is not likely to fail during normal weather conditions and may not fail in severe weather conditions within the specified time frame.

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- Branch with shear plane failure and years of woundwood development.
- Codominant stem with U-shaped union without included bark.
- One-sided crown with no other trunk or root conditions.
- Trunk with seam and no heartwood decay.
- Trunk with less than one-third of the central heartwood decayed.
- Leaning tree with vertical growth at the top (corrected lean).
- Tree with minimal damage on visible structural roots.
- A tree or tree part with no visible defects.

*These examples are provided to assist tree risk assessors with categorizing the likelihood of failure. Tree risk assessors should consider loads, load-bearing capacity, response growth, defects, and additional conditions. A three-year time frame was used in these examples; categories may change when other time frames are applied.

Consequences of Failure

The consequences of a tree failing and impacting a target are based on the value of the target and the degree of injury, damage, or disruption that could be caused. The amount of damage depends on the target's susceptibility to harm, size of the tree or tree part, how far it will fall before impacting the target, and the presence of factors that may protect the target from harm.

It is often said that without a target, a tree poses no risk. However, that does not mean that a failure would have no consequences, as trees have value and provide benefits. If a tree fails, the value and benefits associated with that tree are lost or diminished. Therefore, there are always some consequences associated with failure but not necessarily any risk to people, property, or activities.

When assessing consequences, consider the size of the tree that could fail and how the tree failing could impact a target. Generally, a small branch has less potential to cause harm than a large branch, but small branches fail more frequently, and even a small branch could cause personal injury, a power outage, or a traffic disruption. Branches less than 1 in (2.5 cm) in diameter usually are not considered in most tree risk assessments and in many cases, branches less than 2 in (5 cm) diameter are often not considered.

The minimum size branch that should be considered may be specified in the scope of work. For example, the minimum branch diameter may be 4 in (10 cm). If a 4 in (10 cm) diameter branch falls on a house from a height of 10 ft (3 m) above the roof, the amount of damage may be negligible, and no injury to people inside the house would be expected. If the same size branch were to fall from near the top of a large tree with no branches in between to slow it down, more extensive damage could occur.

In estimating how much damage could occur from a tree failure, consider the amount of force with which it is likely to strike the target. A falling tree or branch will gain speed as it accelerates toward the ground. In general, the higher the distance from which a branch falls or the greater the distance from the tree to the target, the greater the force that the tree or branch will have at the point of impact. If the distance from a tree trunk to a well-built, multistory house is short, a tree that fails may simply lean against the house, causing minor damage. But if the distance is large enough that the tree will accelerate significantly before the trunk strikes the house, damage may be much greater.

A variety of protection factors exist. Vehicles and buildings can protect people inside them. Nearby trees, especially if they are larger than the tree being assessed, can also protect a target by slowing or stopping a falling tree or by changing its direction of fall away from the target. Branches on a tree may provide protection to a target. Large branches might slow or stop the fall of a tree and/or cause the direction of fall to change.

If protection factors do not prevent the falling tree from impacting the target they might still reduce the consequences of the impact. By slowing the fall or changing the direction, the force of impact of the falling tree on the target might be reduced. Assessors should consider the effect of protection factors on both likelihood of impact and severity of consequences.

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Categorizing the Consequences of Failure

Consequences of failure and impact can be categorized as follows:

● ***Severe***—*Severe* consequences are those that could involve serious personal injury or death, high-value damage to property, or major disruption of important activities (Figure 3.22).

Examples* of *severe* consequences may include:

- Injury to one or more people that may result in death or disability.
- Extensive damage to or destruction of a high-value structure(s)(e.g., a home or business).
- Widespread, multiple-day power outages, or indirect consequences such as wildfire (see ISA's BMP—*Utility Tree Risk Assessment*).
- Disruption of major transportation corridors that result in large economic losses or obstructed access to critical emergency services.

● ***Significant***—*Significant* consequences are those that involve significant personal injury, substantial damage to property, or considerable disruption of activities (Figure 3.23).

Examples* of *significant* consequences may include:

- Personal injury requiring professional medical care.
- Serious damage to or total loss of a vehicle.
- Damage to a structure (e.g., a home or business) that is expensive to repair.
- Medium-duration power outages to many customers or damage to utility facilities (see ISA's BMP—*Utility Tree Risk Assessment*).
- Disruption of arterial traffic that causes an extended blockage and/or rerouting of traffic.

● ***Minor***—*Minor* consequences are those that involve minor personal injury, low- to moderate-value damage to property, or some disruption of activities (Figure 3.24).

Examples* of *minor* consequences may include:

- Injury to a person, not requiring professional medical care or hospitalization.
- Damage to a structure or vehicle requiring inexpensive repair.
- Short-term power outage to a few customers or minor utility facility damage (see ISA's BMP—*Utility Tree Risk Assessment*).
- Temporary blockage or disruption of traffic on a secondary street.

● ***Negligible***—*Negligible* consequences are those that involve no personal injury, low-value damage to property that can be replaced or repaired, or short-term disruption of activities (Figure 3.25).

Examples* of *negligible* consequences may include:

- Cosmetic damage to a structure or vehicle that may or may not be repaired.
- Low-value damage to infrastructure.
- Short-term power outage to a house (see ISA's BMP—*Utility Tree Risk Assessment*).
- Temporary disruption of traffic on a neighborhood street.
- Damage to a lawn or landscape bed.

*These examples are provided to assist tree risk assessors with categorizing the consequences of failure and impact. Tree risk assessors should also consider the target, size of the tree part, distance of fall, and protection factors that could affect the categorizations.

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E. Thomas Smiley

Figure 3.22 *Severe* consequences of failure. Failure of this tree could involve serious personal injury or death, high-value property damage, or disruption of important activities, making the consequences rating *severe*.

E. Thomas Smiley

Figure 3.23 *Significant* consequences of failure. Failure of a branch from the large oak (*Quercus* spp.) pictured here could cause major damage to the house or cars. Therefore, the consequences of failure would be categorized as *significant*.

E. Thomas Smiley

Figure 3.24 *Minor* consequences of failure. If this tree failed, it would impact the fence and smaller branches could reach the road, which could cause some vehicle damage or traffic disruption. This is an example of *minor* consequences of failure.

Julian A. Dunster

Figure 3.25 *Negligible* consequences of failure. There are no targets of significance within the target zone of this tree, so the consequences of failure are *negligible*. The greatest loss in this situation would be the tree itself.

Casey Jones

Figure 3.26 The consequences of a large tree falling on an unoccupied parked car are considered *significant*. If the car were occupied, the consequences to a person would be considered *severe*.

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The consequences of the large tree failure shown in Figure 3.26 will be different for different targets. If the tree struck an unoccupied car, the consequences could be *significant*. If the tree struck a person in the car, the consequences would be *severe*. Combining the consequences with the likelihood of failure and impact determines the risk rating.

Often there are many targets, and it may not be feasible to assess all of them. In those cases, prioritize and assess the highest-value targets. For example, if the target zone encompasses a sidewalk, parking area, a fence, and a trellis, it may be adequate to evaluate only the people (using the sidewalk) and vehicles (occupying the parking area) as targets.

Luana Vargas

Figure 3.27 If a 4 in (10 cm) diameter branch falls on a house from a height of 10 ft (3 m) above the roof, the consequences rating would be *negligible*, and no injury to people inside would be expected. If the same size branch were to fall from near the top of a large tree with no branches in between to slow it down, more extensive damage could occur.

Stratifying and Prioritizing Targets

Stratifying (systematic grouping) is a process for classifying targets, and **prioritizing** is a process for ranking targets according to importance or value. Using this process can be helpful when assessing large populations of trees that have a wide range of targets or when assessing an individual tree that has many targets.

Tree populations are sometimes stratified based on target importance to:

a) establish the frequency or even the need for tree risk assessments,

b) establish occupancy rates for Level 1 assessments,

Bryan Kotwica

Figure 3.28 A falling tree will gain speed as it falls. In general, the greater the distance from the tree to the target, the greater the force that the tree will have at the point of impact. If the distance between the tree and the target is great enough, damage may be minimal.

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c) assign time frames for assessments, or

d) establish reassessment intervals.

One method of stratifying target areas when conducting risk assessment is to consider management levels. For a municipality, stratification may have already been done by the risk management department as part of a larger emergency preparedness policy. There are no absolute rules but, typically, the highest-priority target areas include the following:

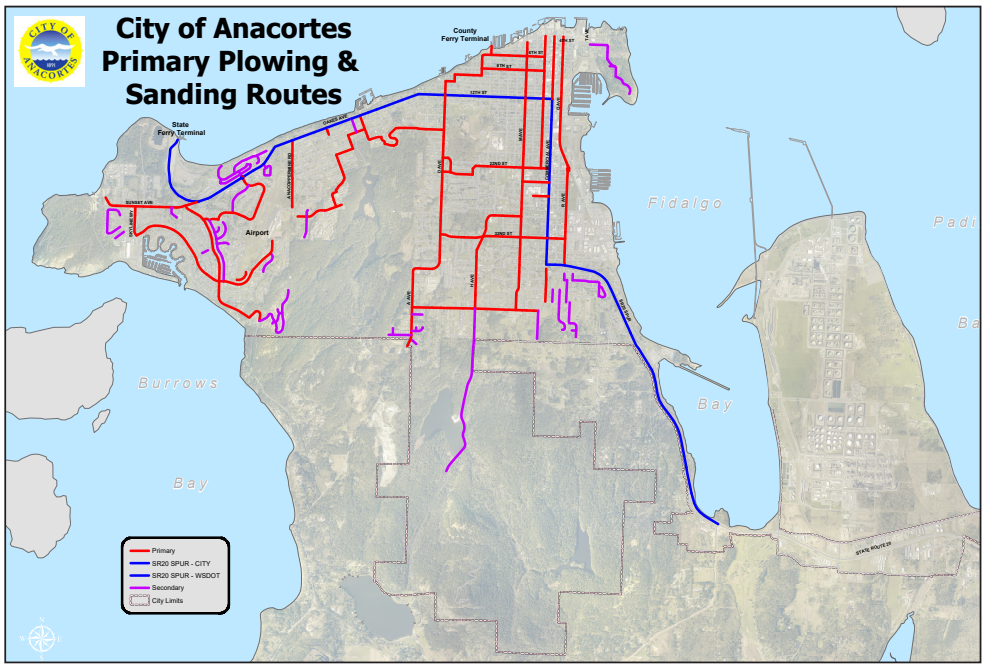
- Critical locations such as hospitals, fire and police stations, and ambulance centers
- Main access routes and transportation sites such as airports, harbors, and train stations
- Main arterial roads linking these places

In the event of a severe storm, these areas become critical sites and routes that must be kept open.

E. Thomas Smiley

Figure 3.29 Protection from falling trees or branches may be provided by structures or other trees. Substantial building structures provide protection against injury to people inside them.

Stratification at a local or neighborhood level would typically establish main roads, busy intersections, bridges, bus shelters, pedestrian crossings, and areas that have *constant* or *frequent* use as high-priority areas. Shorter reassessment intervals may be justified in these areas to identify trees with a higher likelihood of failure and impact.



The City of Anacortes, WA

Figure 3.30 Existing city emergency or disaster response maps plot priority access routes, as indicated by the colored lines. This information can also be applied to the priority areas for tree risk assessment.

Site-specific land uses such as parks or golf courses can also be stratified by priority. Questions to ask include: Where are

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Julian A. Dunster

Figure 3.31 Stratification at a local or neighborhood level would typically identify high-priority areas, which often include main roads, busy intersections, bridges, bus shelters, pedestrian crossings, and areas that have *constant* or *frequent* use.

cars parked? Is there a concession stand or toilet facility where people congregate for longer periods of time (higher occupancy rates)? Where will people congregate during a storm? These questions can help the assessor and risk manager assign occupancy rates.

Using golf courses as an example, the areas with greatest use tend to be the entrance road, the parking lot, the clubhouse, and the main paths to and from the course. Tees and greens are areas where people stay for longer periods of time. Cart paths and fairways may be lower priority because the occupancy rate is usually lower than places such as the clubhouse. The maintenance building area is constantly in use during most days.

Julian A. Dunster

Figure 3.32 Site-specific land uses, such as golf courses, can be stratified and prioritized. The heaviest use areas are the access roads, parking lots, clubhouse, and the main paths to and from the course (higher frequency, lower exposure time). Tees and greens are areas where people congregate less often but for longer periods of time (lower frequency, higher exposure time). Cart paths and fairways have even less use (lower frequency, lower exposure time).

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Summary

In tree risk assessment, targets are people who could be injured, property damaged, or activities disrupted by a tree failure. Risk assessment is undertaken when there is a target of concern. Understanding the importance of the target is a key part of risk assessment, whether for one tree or many trees. The targets are identified, and the potential consequences evaluated. The type of target has a direct connection to the likelihood of impact and that depends on the occupancy rates.

A primary goal of tree risk assessment is to provide information about tree risk—specifically, the level of risk posed by a tree over a specified time frame. In qualitative tree risk assessment, this is accomplished by categorizing the likelihood and consequences of an event. These factors are determined by categorizing:

a) the likelihood of failure of a tree within the specified time frame,

b) the likelihood that a failed tree could strike a person(s) or property or disrupt activities within the specified time frame, and

c) the consequences of the failed tree impacting the target.

Key Concepts

1. The target zone is the area in which the tree is likely to strike when it fails. For a whole tree that is growing on level ground and not leaning, the target zone is generally defined by a circle around the tree with a radius of 1 to 1.5 times the tree height.
2. The most important target is a person. The greatest risk occurs in situations in which many people are unprotected within the target zone for long periods of time, especially during storms.
3. A static target is one that is fixed or not readily moved. Movable targets are those that can be relocated, such as sculptures, information boards, picnic tables, parked cars, or playground equipment. A mobile target is one that is in motion or intermittently moving, including people. The type of target affects the occupancy rate—the amount of time the target is in the target zone. The four categories for occupancy rate are *constant*, *frequent*, *occasional*, and *rare*.
4. Stratifying (systematic grouping) is a process for classifying targets, and prioritizing is a process for ranking targets, according to importance or value. Using this process can be helpful when assessing large populations of trees that have a wide range of targets or when assessing an individual tree that has many targets.
5. The time frame is the specified length of time for which the assessor is considering the likelihood of failure and impact. The time frame is usually decided with or specified by the tree risk manager and is included in the scope of work.
6. The likelihood of impact is the chance that if the tree fails, it will strike a target during the specified time frame. The occupancy rate is the primary factor for determining the likelihood of impact, but two other considerations are target protection factors and the direction of fall. The four categories for likelihood of impact are *high*, *medium*, *low*, and *very low*.

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7. The likelihood of failure is the chance of a tree failure occurring within the specified time frame. Many factors must be considered when categorizing the likelihood of failure. These include site and weather conditions, tree health, loads, tree defects and other conditions that can decrease tree load bearing capacity, and growth adaptations that can increase tree load carrying capacity. The four categories for likelihood of failure are *imminent*, *probable*, *possible*, and *improbable*.
8. The consequences of a tree failing and impacting a target are based on the value of the target and the degree of injury, damage, or disruption that could be caused. The amount of damage depends on the target's susceptibility to harm, size of the tree or tree part, how far it will fall before impacting the target, and the presence of factors that may protect the target from harm. When assessing consequences, consider the size of the tree or tree part that could fail, and how it could impact a target. The four categories for consequences of failure are *severe*, *significant*, *minor*, and *negligible*.

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Site Assessment

Module 4

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Site Assessment

Module 4

Learning Objectives

- Recognize and discuss how a site influences the growth and development of the trees present.
- Identify and describe the key site factors that influence the likelihood of tree failure.
- Discuss the key terms and concepts related to site assessment for tree risk assessment.
- Recognize weather conditions that affect trees on a site, including the effects of wind exposure.
- Recognize common indications of previous failures on a site.
- Assess and discuss the interactions among past site changes, tree growth, and weather patterns, and anticipate how these might affect the short- and long-term stability of the trees.

Key Terms

aspect	grade changes	precipitation	suppressed
Beaufort scale	history of failure	response growth	topography
codominant	interior tree	severe weather	wind exposure
dominant	load	soil compaction	wind load
edge tree	load-bearing capacity	soil hydrology	wind velocity
extreme weather	normal weather	subdominant	windthrow
forest stand	open-grown trees		

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Introduction

The goal of site assessment is to identify the site factors that may affect the likelihood of failure, the likelihood of impact, or the consequences of failure.

When performing a basic assessment, site conditions are visually assessed. Start with a broad perspective of the site. Walk or drive around the site. Look at the landform, overall site, and tree characteristics. Get a sense of the environmental conditions and what they mean. Conditions below ground might be inferred by observing growth patterns of nearby vegetation, tree root failures, roadcuts, or the assessor's knowledge of the area. In some cases, an advanced assessment may be warranted to investigate site conditions not visible during the basic assessment.

Healthy trees can often respond to altered growing conditions and loads, but that takes time. Some changes are too great and there may not be enough time for the tree to adapt leading to an increased likelihood of failure within the stated time frame.

Assessors should learn to read the landscape to identify and interpret site factors that are relevant to risk assessment. Understanding the site will help to inform an assessor's observations as they move from the broader context of the site to tree-specific details.

Site Factors

Site factors influence tree root system stability, growth, and the **loads** a tree experiences. Site characteristics that may be observed, described, and, in some cases, investigated include:

- **Weather patterns** in the area, especially wind and precipitation
- **Growing conditions** for one or more trees
  - **Wind exposure**
  - Sun exposure
  - Effect of wind exposure on tree growth
  - General forest characteristics (species, age class, conditions)

Definitions of Some Key Terms

Several key terms are required for understanding site assessment. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

Beaufort scale—a means of categorizing wind speed on a scale of 1 to 12.

history of failure—evidence of past tree failure within a tree or on a site.

load—a general term used to indicate a force, bending moment, torque, or pressure applied to a structure, structural member, or material.

load-bearing capacity—the capacity of a structural member or material to carry a load before it fails.

response growth—new wood produced in response to loads to compensate for greater strain in marginal fibers; includes reaction wood (compression and tension), flexure wood, and woundwood.

weather categories:

normal weather—weather based on a location's average temperature, wind speed, and precipitation for the previous 30 years.

severe weather—weather that has the potential to cause damage including strong winds and storms (e.g., thunderstorms, freezing rain).

extreme weather—severe weather that is historically infrequent for the region and has the potential to cause devastating damage. Extreme events include blizzards, floods, tornadoes, heavy accumulations of snow or ice, and tropical cyclones (hurricanes and typhoons).

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- Topography, including slope and aspect
- Land-use history and changes

- **Soil conditions**
  - Volume
  - Depth of soil profile to bedrock or hardpan or water table
  - Moisture regime over a year (drainage characteristics, flooding potential)
  - Texture (silty, sandy, loamy)
  - Disturbances (recent or long ago) such as compaction, restrictions to root growth, impermeable layers, roads, urban infrastructure, or building foundations

- **History of failures** at the site, especially live trees that have fallen down

- **Site changes**
  - Tree removals
  - Construction activity
    - Grade changes
    - Site clearing
    - Changed hydrology

Weather

Most tree failures occur during periods of strong wind, heavy precipitation (rain, snow, ice), or both (e.g., blizzards, thunderstorms). During such events, site factors such as soil moisture, wind speeds or wind directions may change drastically. As a result, the loads a tree experiences are greater than normal, the strength of component parts may be exceeded, or the soil and root interactions may be weakened, which may compromise the tree's load-bearing capacity.

A tree risk assessor should be familiar with the typical weather patterns in the area where they work. Weather is typically classified based on its intensity and frequency of occurrence. In the United States, the National Weather Service defines three broad weather categories: normal weather, severe weather, and extreme weather.

E. Thomas Smiley

Figure 4.1 When wind speeds exceed strong gale force (Beaufort scale 9), even defect-free trees can fail.

Normal weather is based on a location's average temperature, wind speed, and precipitation for the previous 30 years. In some areas, strong winds that are considered normal often occur multiple times within the defined time frame. Normal storms may include thunderstorms or light accumulations of snow or freezing rain in areas that typically experience those conditions.

Severe weather is defined by having the potential to cause damage. Severe weather events can include severe thunderstorms or accumulations of snow or freezing rain. Severe weather events may occur during the specified time frame of the risk assessment.

Extreme weather is defined as severe weather that is historically infrequent and not expected within the time frame of the risk assessment. It has the potential to cause devastating damage. Extreme events include blizzards, tornadoes, heavy accumulations of snow or ice, and tropical cyclones (hurricanes and typhoons).

Wind

Load on a tree increases with wind speed, which is affected by terrain and topography. In urban areas, wind speed varies depending on the location in the landscape. Infrastructure and groups of trees can reduce or increase wind speed. Wind speed increases as elevation and the height above ground increase.

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The Beaufort Scale

The **Beaufort scale** is a commonly used means of categorizing wind speed on a scale of 1 to 12. Force 9 is a strong gale with a wind speed of 47 to 54 mph (76 to 87 kph or 21 to 24 m/s); this is normal in many areas. Tree failures at or below this level are often associated with serious defects or conditions that affect a tree's load-bearing capacity.

Force 10 is a storm with wind speed of 55 to 63 mph (88 to 101 kph, 25 to 28 m/s); in many areas these wind speeds are considered severe. Tree damage may be expected.

Force 11 is a violent storm with wind 64 to 72 mph (102 to 116 kph, 29 to 32 m/s). Force 12 is hurricane-force with winds greater than 73 mph (117 kph; 33 m/s). These wind speeds are considered extreme in most places. At these wind speeds, failure of defect-free trees can be widespread.

Force	Wind		Classification	Effects on Land
	MPH	KPH		
0	< 1	< 1	Calm	Smoke rises vertically.
1	1 to 3	1 to 5	Light air	Smoke drift indicates wind direction, vanes do not move.
2	4 to 7	6 to 11	Light breeze	Wind felt on face, leaves rustle, vanes begin to move.
3	8 to 12	12 to 19	Gentle breeze	Leaves and small twigs move constantly, light flags extend.
4	13 to 18	20 to 28	Moderate breeze	Dust, leaves, and loose paper lifted up, small tree branches move.
5	19 to 24	29 to 38	Fresh breeze	Small trees begin to sway.
6	25 to 31	39 to 50	Strong breeze	Large tree branches move, whistling heard in wires.
7	32 to 38	51 to 61	Near gale	Whole trees move, resistance felt walking against wind.
8	39 to 46	62 to 74	Gale	Twigs and small branches break off trees, generally impedes walking.
9	47 to 54	75 to 87	Strong gale	Slight structural damage occurs, shingles blow from roofs.
10	55 to 63	88 to 101	Storm	Trees broken or uprooted, considerable structural damage.
11	64 to 72	102 to 116	Violent storm	Widespread damage to vegetation and structures.
12	73+	117+	Hurricane	Widespread damage/destruction of vegetation and structures.

Adapted from the National Oceanic and Atmospheric Administration (www.spc.noaa.gov/faq/tornado/beaufort.html)

Wind speed is decreased by surrounding trees and sometimes by nearby buildings. Wind speed is also reduced by nearby trees of similar size or larger than the subject tree.

Buildings can both increase or decrease wind speed. Large buildings lining a city center street can create a funneling effect. Wind speed is typically highest at the corners of buildings.

When evaluating wind loads during tree risk assessment, the assessor should consider the normal range of weather conditions for the region within the assessment time frame. For example, strong winds may be within the range of normal conditions, but a tropical cyclone or tornado would not be within that range.

Skip Kincaid

Figure 4.2 The manner in which wind moves around a tree will depend on several factors, including the height of the tree and the shape, extent, and openness or porosity of the crown.

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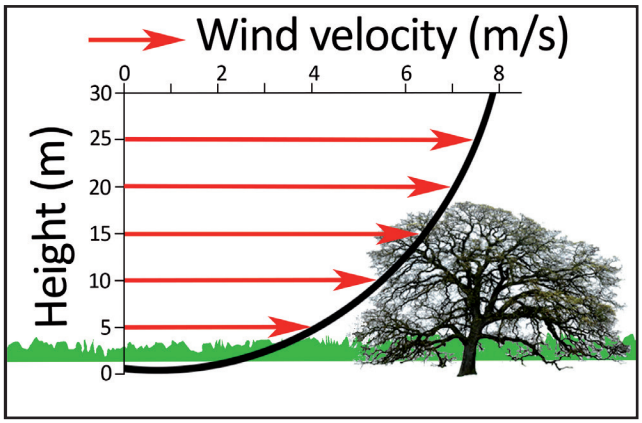
Trees and Wind

Over time, trees respond to the loads they commonly experience. Trees exposed to consistent and strong winds from a single direction grow a streamlined crown that appears to flow away from the wind. This growth pattern is an adaptation to decrease the likelihood of failure. In a similar adaptation, a tree fully exposed to the wind will grow a more tapered trunk than a tree sheltered from the wind. If the sheltered tree is suddenly exposed to the wind, it will fail at a lower wind speed than the tree that grew with continuous wind exposure, unless it has enough time to adapt to the new loading conditions. This situation can occur when a forested site is partially cleared for development.



Julian A. Dunster

Figure 4.3 Generally, the velocity of a sustained wind increases with height.

Expected weather patterns for a site are important because, over time, trees respond to the loads they commonly experience by adding wood for support (see "Trees and Wind" sidebar). Trees grow to withstand higher than normal loads. However, when winds are strong enough, even defect-free trees can fail. When wind speeds reach hurricane force, failure of defect-free trees can be widespread.

Tree failures during normal wind speeds are often associated with serious, uncorrected, or unmitigated structural defects or other conditions, which can occur alone or in combination.

Precipitation

Another important weather factor is **precipitation** in the form of rain, snow, and freezing rain. Rain can add 25 to 50 percent to the weight of a branch with leaves attached, but by itself, rain is less likely to cause branch or trunk failure. Snow can add at least three times the weight of a branch, depending on the species and where the branch is located in the crown. Ice can add 20 to 30 times the weight of a branch. The accumulated weight of precipitation can sometimes be enough to cause branch failure. If the accumulation occurs in conjunction with wind, the likelihood of branch failure is increased further. Ice storms can cause widespread branch failure.

Rain also affects the likelihood of root and soil related tree failures. Trees are more susceptible to root and soil failure (**windthrow**) when the soil is saturated because there is less friction between the roots and soil. Less friction also weakens the soil itself, which can also contribute to windthrow. This is particularly true when tree roots are shallow. Rooting depth is a species-specific characteristic, or a result of shallow soil depth. Most trees adapt to their site conditions, but sudden changes such as removing adjacent trees, building new infrastructure, compacting the soil, or altering drainage patterns can affect root growth and loading. With excessive rain or increased water flow toward a tree, even deep, well-drained soils may become waterlogged and unpredictable soil failures are possible.

Tree Exposure

Wind Exposure

Wind load on a tree depends on the wind speed and the degree to which the tree is exposed to the wind. Categories of exposure are:

- Protected
- Partially exposed
- Fully exposed
- Wind funneling

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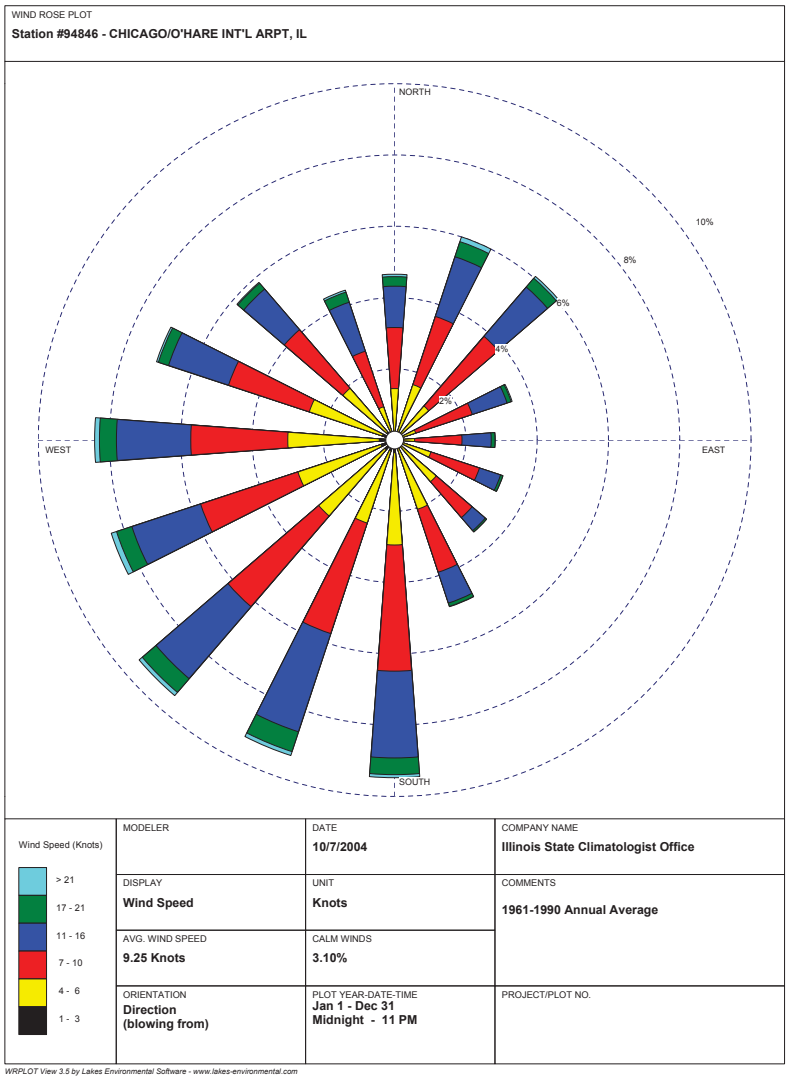

Illinois State Climatologist Office

Figure 4.4 Understanding typical wind patterns on a site may help an assessor locate adaptive growth patterns. A wind rose shows the occurrence of wind speed and direction at a site and may be available from nearby weather stations. Software is also available to model regional or local wind patterns as part of an advanced (Level 3) risk assessment. In this example, the strongest winds occur from the south to southwest quadrant with the highest frequency.

Protected trees are those located in the middle of a group of trees, in the interior part of a forest, or surrounded by buildings.

Partially exposed trees are typically found along the edge of a group or forest, or where some similar sized or larger trees are nearby, and near to buildings.

Fully exposed trees are those not adjacent (> 1 × tree height away) to other trees or tall buildings.

Wind funneling occurs in urban or natural canyons or valleys, at the corners of buildings, or where plants or structures redirect wind into a smaller area, thus increasing **wind velocity**.

Sun Exposure

In addition to wind, trees are also exposed to the sun. Often, sun and wind exposure are related. Trees on the edge of a stand of trees are partially or fully exposed to the wind and are exposed to sunlight mostly from one side. As a result, their trunks have greater taper to bear the greater wind loads. Well-established **edge trees** also tend to have two obvious characteristics: (1) the branches will mainly be on the open side with fewer on the side toward adjacent trees, and (2) they may be leaning toward the opening as a result of phototropic growth. In some cases, the lean may be greater due to the one-sided crown.

Effect of Exposure on Tree Growth

Open-grown trees are fully exposed to the wind and do not compete for light. In these conditions, they often grow wider crowns to maximize leaf area. They may also grow more tapered trunks and branches to bear greater loads from wind and gravity. Unless they experience wind from a single direction (as sometimes happens along coastlines or the tops of mountains) or the belowground conditions restrict their development, the root system will develop symmetrically around the trunk.

When trees are consistently exposed to wind from a single direction, they tend to grow in ways to both reduce exposure to the loads and increase load-bearing capacity in that direction. Crowns tend to grow into a more streamlined shape, and root systems tend to develop asymmetrically, with rope-like tension roots on the windward side. If these

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E. Thomas Smiley

Figure 4.5 The accumulated weight of snow or ice can greatly increase the load on a branch and can cause failure.

E. Thomas Smiley

Figure 4.6 Trees are more susceptible to windthrow when the soil is saturated. In this example, a lack of soil volume may also have been a contributory factor.

roots have been damaged, severed, or decayed, the likelihood of root failure will be increased.

Especially in wooded (or previously wooded) areas, assessors may be able to identify **dominant**, **codominant**, **subdominant**, and **suppressed** trees. Doing so can provide clues to the tree's past exposure to wind and the load-bearing capacity it developed in response. Dominant trees are more likely to have been subjected to stronger and more variable winds for most of their life. They will most likely have a fuller crown and a root system with greater load-bearing capacity. Codominant trees (as used in forestry, and not to be confused with "codominant stems" of a single tree) are protected from the wind, and their movement is limited by adjacent trees. As a result, their root systems may be less well developed than those of dominant or open-grown trees. Removing one or more dominant or codominant trees in a stand may destabilize the remaining trees. Subdominant understory trees will have less well-developed crowns, and their root systems will have lower load-bearing capacity. Suppressed trees are the smallest in the forest canopy, and tend to be spindly, less vigorous, and have small root systems. They will be the least stable trees if the surrounding trees are removed.

Topography

A site's **topography**—the physical features, elevation, and changes in elevation—can affect characteristics such as wind load and soil moisture, which can, in turn, affect the likelihood of failure.

Slope

When the site is not level (or flat), it has some amount of slope. The slope can be visualized as the angle of the site relative to a level surface; it is usually expressed in degrees (e.g., "a slope of ten degrees") or as a percent (e.g., "a slope of five percent"). The larger the degree or percent, the steeper the slope. The amount by which a landform slopes is determined by the underlying bedrock and soil type. Steeper slopes are potentially less stable than gentle slopes and may have thinner layers of soil that are more susceptible to mass movement of the upper soil layers (slope creep or landslides). Slopes that

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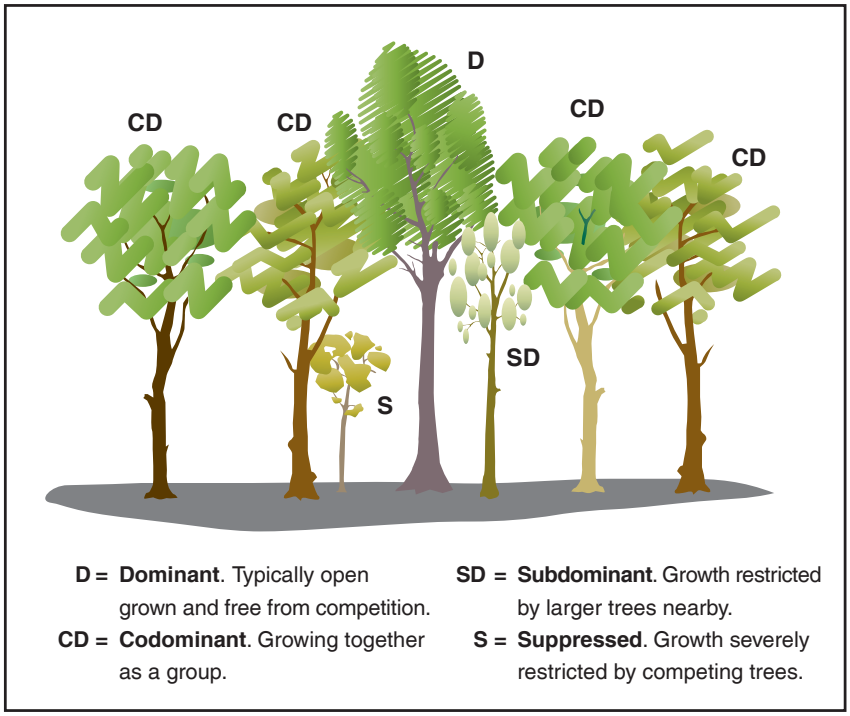
are creeping (moving downhill due to gravity) can sometimes be detected by looking for a characteristic "J" shape at the base of tree trunks. Usually, the soil at the top of the slope will be well drained, while soil at the bottom of the slope will be wetter, possibly even waterlogged, as water from the upper slope drains and accumulates at the bottom. Assessors can use a soil probe to determine the depth and penetrability of the soil. Trees growing on unstable soils and slopes will fail when the slopes fail.

Aspect

If the site has a slope, it also has an **aspect**; the aspect is the direction that the slope faces. One way to understand the aspect is to visualize which direction a ball would roll if placed on the slope. On a steep slope with a northern aspect, or facing north, a ball placed on the ground would roll northward. To determine the aspect of a slope, an assessor can use a compass (or a compass app) to determine the downslope direction. The aspect will be most obvious on a site with a steeper slope.

Soil Conditions

Site soil conditions influence both tree health and stability. Health is affected by soil volume, depth, moisture level, and nutrient availability. If all are available at adequate levels, the tree can develop leaves to produce carbohydrates which can then provide the energy to develop branches and grow the trunk and root system. A well-developed root system provides better water and nutrient uptake. It also provides the necessary load-bearing capacity to keep the tree upright.



Bryan Kotwica

Figure 4.7 Trees growing in wooded areas are affected by the surrounding trees in several ways, including light availability, wind exposure, and root system overlap. This graphic illustrates the relationship of dominant, codominant, subdominant, and suppressed trees in a forest canopy. Changes to the wooded area can affect loading.

Joe Kellerhals

Figure 4.8 Trees that have grown up in the interior part of a forest will have lower load-bearing capacity because they have not experienced the loads that trees along the edge and open-grown trees have. Interior trees that have been abruptly exposed (e.g., from construction, storm damage, or land clearing) may have an increased likelihood of failure.

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Effects of Slope Aspect

The aspect (compass direction) affects slope profile and **soil hydrology**. Typically, in the Northern Hemisphere, a north-facing slope will be colder and wetter because it receives less direct sunlight. North- and east-facing slopes will usually have thinner soils and will be much rockier. South- and west-facing slopes are usually hotter, drier, and may have deeper soil profiles. They receive more direct sunlight all year long. The soil and rock weathering processes are much more pronounced on south and west exposures, and the vegetation growing on these areas will be very different from that growing on north or east exposures. In the Southern Hemisphere, the slope descriptions are reversed: south- and west-facing slopes will be colder and wetter. Differences in soil and vegetation can impact root depth and development, which can, in turn, affect tree stability. Trees with deeper, more extensive root systems tend to be more stable.

It is reasonable to assume that if a young tree has developed into a large tree, there is adequate soil volume, depth, moisture, and nutrients to sustain the tree. The next question is whether the soil can continue to support the tree as it grows larger.

Soil factors to consider include:

- Volume
- Depth
- Moisture
- Quality (e.g., texture, nutrients, organic matter)
- Disturbances that affect any of the above

Soil Volume

The volume of soil needed to sustain and support a tree depends on its species and size, as well as soil moisture and nutrient availability. Trees need to be connected via their root system with a large enough mass of soil to keep the tree upright during dynamic loading. In general, limited soil volume will affect tree growth as well as stability. An underdeveloped or distorted root system may not only be structurally weak, but it may also greatly limit tree health and diminish the tree's ability to adapt to the loads.

Limited soil volume is common in urban areas where space is at a premium and root damage is common. Soil volume is limited by urban infrastructure such as building foundations (e.g., footings, basements), roads, soil cuts, and surface soil compaction. Surface **soil compaction** is common where vehicle or pedestrian traffic occurs. Compaction reduces pore space, and, as a result, there is less room for gas exchange or moisture retention. In addition, roots within a compacted soil may be physically crushed or damaged, leading to weakness, decay, or death.

Soil depth can limit the overall soil volume available by limiting downward root growth. Most lateral roots develop in the upper layers of the soil profile where there is sufficient air, moisture, and nutrients. Within the dripline, some species develop sinker roots that grow directly downward from lateral roots. Sinker roots can add greatly to tree stability.

Joe Kellerhals

Figure 4.9 A soil probe can be used to determine soil depth and penetrability. Here, the arborist is determining soil conditions under the pavement.

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Depending on soil depth and tree species, oblique roots can develop and grow at a downward angle radiating outward from the trunk. This type of root system is sometimes referred to as a heart root system. It can allow a tree to be more resistant to the effects of nearby trenching or **grade changes**.

Joseph O'Brien

Figure 4.10 Shallow root systems are associated with saturated soils or over-irrigated landscapes.

A taproot is a downward-growing root directly below the main stem. Taproots are not commonly found on most urban trees because they were removed in the nursery, or at transplanting, or downward growth was limited by soil depth. Trees with taproots tend to be least affected by nearby trenching or grade changes. Shallow soils can occur naturally when there is underlying bedrock, compacted subsoil, or built infrastructure near the soil surface. They can also be developed when the water table is close to the soil surface or when a landscape is poorly drained and overirrigated.

Trees develop shallow root systems in shallow soils. Shallow root systems are often indicated by the presence of surface roots. If the rooting depth is shallow, a wider, more extensive root system is needed to support the tree. With the same soil volume (radius), shallow-rooted trees are more prone to failure than those with deeper root systems.

Soil Moisture

Soil moisture levels affect both tree health and stability. Adequate moisture levels are required for nutrient uptake from the soil and translocation throughout the tree. Moisture level can affect the rooting depth of the tree by limiting downward root growth with excessive water and limiting the growth of roots near the soil surface with a lack of moisture.

Moisture is one of the factors that affects soil cohesion and shear strength. Saturated soils have a lower strength and therefore cannot limit root movement as well as drier soils. This can result in numerous soil-related, whole-tree failures when soils are saturated and there is sufficient wind.

The amount of rain and irrigation on the site greatly affect the soil moisture level. In the time of human caused climate change, we can expect greater extremes in rainfall. Heavy rain events, or high levels of rain over many days or weeks, tend to cause soil saturation.

Irrigation can be used to maintain adequate levels of soil moisture during periods of drought. This can greatly improve tree health. However, roots may be damaged if the irrigation is not matched to site conditions and species needs, and tree failure may be more likely if the soil is saturated.

Soil drainage can also affect moisture levels. Poorly drained soil restricts movement of excessive amounts of soil moisture out of the upper layers of soil. Soil may be poorly drained due to texture (clayey soil), compaction, underground infrastructure, high water tables, or bedrock.

Soil Quality

Root development is also affected by the quality of the soil, such as its texture, nutrient levels, and

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organic matter. Soil texture affects soil moisture: coarse-textured sandy soils will drain quickly, while fine-textured silty and clayey soils will drain more slowly. Changes in soil moisture levels, especially percolation rates, directly affect root development.

The availability of adequate soil nutrients directly affects tree growth and development. Nutrient deficiencies can cause physiological stress in trees, affecting root growth and health, as well as tree defenses. Soil organic matter is an important factor in soil quality because it is an integral part of the soil ecology, including decomposition, microbial activity, and nutrient cycling. Organic matter also retains available water, releases nutrients, and supports the soil structure.

Soil Disturbances

Any soil disturbance, such as from land development, can not only kill or sever roots directly but also damage soil, making other issues worse. Soil compaction is common where vehicle or pedestrian traffic occurs. Compacted soil has reduced pore space, and, as a result, there is less room for gas exchange or moisture retention. In addition, roots within a compacted soil may be physically crushed or damaged, leading to weakness, decay, or death.

On most sites, the assessor cannot examine the root system without conducting an advanced (Level 3) assessment. Soils can be assessed through probing, laboratory analysis, moisture testing, and sometimes by reviewing site or development plans. Soil testing and/or analyses are not typically performed in tree risk assessments but may be necessary in situations where soil windthrow or root failure are serious concerns. Assessors should decide whether to probe, sample, or test the soil based on an understanding of tree biology and experience with risk assessments. Even if soil testing is not justified, assessors should consider how site factors may have influenced the development of root systems.

History of Failures

Evidence of previous tree failures on the site can provide clues to site conditions that increase the likelihood of tree failure. Nearby trees experienced similar weather patterns and site changes, and observations of previous failures may be indications of site issues to be examined. For example, multiple failures in an area might indicate compacted, saturated, poorly drained, or shallow soil; root disease; construction damage; or a location that experiences strong winds. In addition, a windstorm that uprooted many trees may have left others standing but unstable.

Look for signs of past failures such as stumps, fallen or leaning trees (including signs of root or soil failure), broken or hanging branches, branch stubs, and scars from branch failures. Look also for signs of pruning, support system installation, or other mitigation measures that might have been taken to reduce risk in the past. Look for signs of site changes

Luana Vargas

Figure 4.11 Root health is important, so look for indications of how site conditions affect root development. Surface soil compaction is common where vehicle or pedestrian traffic occurs.

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and disturbances, such as construction damage. Examination of upturned root plates and visible soil profiles may reveal root disease or high water tables.

Site Changes

Site changes can damage supporting roots and affect the intensity and/or direction of loading. Site changes include events such as forest clearing, soil cuts and fills, and excavations during demolition or addition of structures.

For example, retaining a single tree after clearing a forested site can increase the intensity of wind loading on the retained tree. In addition, tree damage during clearing operations can reduce the load-bearing capacity of the tree's root system. A change in load, load-bearing capacity, or both can increase the likelihood of tree failure.

It can be useful to know the tolerance of local tree species to changes in site conditions.

Joe Murray

Figure 4.12 Activities such as moving heavy equipment across the roots, raising or lowering the existing soil grades, and trenching to install utilities or irrigation systems can damage roots and increase the likelihood of failure. Such activities can alter the water table and soil hydrology as well, leading to decline and failure after development.

Assessing the Site

Any site activity that alters the conditions to which trees have adapted has the potential to affect tree stability. In areas where new development is underway or being proposed, one or more site factors may be changed. Changes to consider include the following:

- Altered wind patterns and velocity due to structures funneling or blocking wind
- Altered levels of sunlight exposure due to new structures and removal or planting of adjacent vegetation
- Changed soil moisture regimes due to compaction, altered natural waterways, installed subsoil drains, or grade changes
- Damaged root systems resulting from compaction; grading; excavation for basements or footings; or installation of underground utilities, services, landscape lighting, or irrigation systems

Wind Exposure

Try to determine whether trees that are fully exposed were always fully exposed. If they recently became exposed as a result of clearing neighboring trees or removing buildings, their likelihood of failure may well be higher. Open-grown, dominant, and edge trees tend to be well adapted to prevailing winds at a site. But **interior trees** of a **forest stand** will not have developed the same load-bearing capacity because they experienced lower loads as they developed. If such trees are abruptly exposed (for example, from construction, storm damage, or land clearing), they may have a higher likelihood of failure.

There may be times when an assessor considers trees in wooded or formerly wooded areas. Because trees grow according to their surroundings, trees growing in wooded areas have different wind exposure and will develop differently than open-grown trees. In a wooded area, trees compete for light, so they tend to grow taller rather than wider. And since nearby trees offer protection from the wind, trees in the interior tend to grow more slender trunks that have less load-bearing capacity. Reduced wind loads also

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affect the development of root systems. Interior trees tend to have smaller roots plates as they do not need to provide as much load-bearing capacity. Newly exposed edge trees need time to adapt to the changed wind patterns. If the edge trees are leaning, check to see if they are partially uprooted or if the lean is due to phototropism.

Richard Hauer

Figure 4.13 Any site activity that alters normal site conditions to which trees have adapted has the potential to affect tree stability.

Sun Exposure

New landscapes installed around existing trees often damage the tree, although the damage may be hidden. Some species with thin bark are susceptible to sun scorch. Trees that were once sheltered and are now newly exposed may suffer extensive bark damage and decline.

Soil Conditions

It is difficult to inspect root systems. In a visual assessment, assessors make some assumptions about root development based on what can be seen at the base of the tree and the site conditions. Sometimes a simple probe can be used to determine how penetrable the soil is. A tree that is healthy and growing vigorously is better able to develop **response growth** to maintain good structure and stability over time. Because the health and load-bearing capacity of roots are important, assessors look for indications of how site conditions may have affected—positively and negatively—the development of a tree's root system. For example, the presence of large surface roots may indicate a shallow soil and/or a high water table.

Root Damage

If roots have been damaged or severed, the tree's load-bearing capacity can be reduced. The amount of root loss that can be tolerated varies with species, maturity, crown size, health, site conditions, and climate. As a very general guide, when one-third or more of a tree's structural roots are missing or significantly decayed, load-bearing capacity can be significantly reduced. If one or more large structural roots have been severed within a distance of three times the trunk diameter, look for new root growth or root decay to assess whether the tree has sufficient support. Root loss that occurs beyond that distance may be a stability concern if multiple large roots have been severed or destroyed.

Cut or damaged roots also adversely affect tree health, even if the damage is not enough to meaningfully reduce the tree's load-bearing capacity. Growing new roots or containing damage to existing roots requires energy that would otherwise be allocated to other parts of the tree. Trees with reduced vigor from root damage may not be able to readily develop replacement roots, response growth, and defensive mechanisms to guard against insect pests and disease pathogens.

Grade Changes

Raising the soil grade may damage the existing roots, but it depends on soil texture and how well drained the soil is. In some soils, and assuming the

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Table 4.1 Examples of how site factors influence the likelihood of tree failure.

Site Factors	Likelihood of failure is increased by	Likelihood of failure is decreased or unaffected by
Wind speed	Severe or extreme winds (e.g., hurricane, tornado, microburst) for the site	Normal winds for the site
Soil moisture	Excessively wet or waterlogged soils	Dry soils
Soil depth	Shallow soil, especially if prone to waterlogging	Deep soil
Topography	Top of ridge, newly exposed	Valley, low wind exposure, moderate water
Exposure	Forest stand tree recently exposed	Open-grown tree adapted to exposure

tree is vigorous, the tree may develop a second root system closer to the surface. Under some circumstances, soil placed against the trunk can allow disease or decay to enter the tree, especially if the trunk is wounded. Some species will respond to fill soil against the trunk by developing adventitious roots. Adventitious root systems can usually keep a tree alive, but they might not contribute to load-bearing capacity. As the original and damaged root systems decay, the tree may lack sufficient structural roots to resist normal loads. Assessors should check carefully for evidence of grade changes near existing trees.

Another challenge with raising the soil grade is that assessors cannot inspect the root flare. Without a view of this important part of the tree, it may not be possible to complete the risk assessment without removing the fill soil. In a Level 2 assessment, the assessor should conduct a preliminary assessment at the base of the tree to determine the extent of the fill. In some cases that will be sufficient to understand the situation. An advanced (Level 3) assessment may be required if the fill is deep or other issues of concern underground require further investigation.

Soil hydrology is an important site factor to consider. Changes in the soil hydrology regime can occur slowly as sites adapt to new conditions, but often new development causes major hydrological changes causing altered soil conditions that trees cannot overcome. If soil hydrology changes as a result of site disturbance or drought, the tree's root system, which developed in the undisturbed site, must adapt. Given enough time, and assuming the tree has enough energy reserves, survival may be feasible as the tree grows new roots into soil with appropriate moisture. As this happens, it is not uncommon to see trees slowly decline as they struggle to maintain current foliage while growing new roots. Topography can provide clues that water movement has been disrupted.

If there is evidence of site disturbance, the assessor should try to estimate how long ago it occurred. Did the disturbance occur within the past year, several years ago, or decades ago? The longer the timelapse, the more time the tree will have had to adapt to the change.

Aerial photographs, such as those available through Google Maps™ or Google Earth™, can provide information about the site and adjacent land-use patterns.[1] Some areas may have historical images available to compare land use change over time and the effects on trees.

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CASE STUDY

The Influence of Site Factors

Assignment: The owner of a popular restaurant requested that an arborist inspect their trees and make maintenance recommendations. The arborist recognized potential problems with a western hemlock (*Tsuga heterophylla*) in a parking lot. While the arborist was not originally hired to conduct a tree risk assessment, the arborist expressed their concern about the risk associated with the tree. The owner agreed to a basic tree risk assessment (Level 2) of the western hemlock.

Time Frame: Three years.

Targets and Site: People near the tree including those walking from their cars to the restaurant and maintenance personnel were categorized as *occasional* occupancy. Parked vehicles were categorized as *frequent*. The restaurant building was outside of the target zone.

The parking lot was constructed about ten years ago. Fill soil was added to level the parking area. During construction, tree trunks were protected from mechanical damage, and there was an attempt to maintain the original grade around the trees. This resulted in several trees that are now in low areas that collect runoff water from the parking lot pavement. About half of the trees at the site have been removed. Exposure to wind has increased due to removal of the trees. The site has recently experienced strong winds and heavy rain (severe weather).

Tree Conditions: The western hemlock is in fair health. The length of new twig growth is relatively short and some needles are chlorotic and smaller than normal. The bark has an unusual texture with canker-like symptoms on the lower trunk on the side opposite the parking lot and building.

Soil has accumulated around the trunk of the tree, resulting in the root collar being well below grade. There is a significant gap between the trunk and soil on the side of the tree facing the parking lot and building, indicating that the recent strong winds have caused excessive trunk movement. Other conditions noted:

- Soil is wet due to the rainwater runoff.
- Based on probing the soil, the buttress roots are at least 18 in (45 cm) below grade.
- Root decay or a lack of root support is suspected based on the canker-like symptoms, excess soil moisture, fill soil, and trunk movement.

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Analysis: The likelihood of failure was categorized as *probable* for the three-year time frame. The likelihood of impact for people was categorized as *low*, and for vehicles, *medium*. Combining a *probable* likelihood of failure with a *low* likelihood of impact for people and *medium* likelihood of impact for vehicles in Matrix 1 gives a categorization of *unlikely* for the likelihood of failure and impact for people and *somewhat likely* for vehicles. Consequences were rated as *severe* for people and *significant* for vehicles. Matrix 2 was used to combine the likelihood of failure and impact with the consequences, which resulted in a risk rating of *low* for people and *moderate* for vehicles.

Mitigation Options: 1) Remove the tree. 2) Retention and reassessment is an option, but the likelihood of failure is *probable*, and the condition is unlikely to improve with time or any arboricultural treatment.

There is no practical way to restrict the targets without sacrificing parking spots.

Residual Risk: If the tree is removed, the residual risk of that tree failing is eliminated, but the likelihood of failure of the remaining trees could be affected.

Report: A written report was emailed to the client (tree risk manager), who decided to have the tree removed.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photos by E. Thomas Smiley

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Summary

Before starting the visual assessment of a tree, it is important to assess the site, or the landscape setting where the tree is growing. The site assessment will provide information on site-specific factors affecting an individual tree or a group of trees. It will also provide a better understanding of site use patterns and changes that may have taken place in the past, that are currently underway, or that are planned for the future. Any of these factors can affect the likelihood of failure, the likelihood of impact, or the consequences of failure.

Key Concepts

1. Certain aspects of the site may increase or decrease the likelihood of failure, likelihood of impact, and/or the severity of consequences.
2. Growth and development of a tree are, in part, a response to the loads and conditions the tree has experienced during its lifetime. Site changes may affect the likelihood of failure in the short or long-term. How well a tree adapts to the changed site conditions is related to the tree species, its health and vigor, age, and structural condition.
3. Wind flows over and around natural and artificial physical features, and their interacting slopes and surfaces affect wind speed and direction. Wind speed increases with height.
4. The accumulated weight of precipitation (especially ice) distributed over a tree can sometimes be enough to cause branch or trunk failure. If the accumulations occur in conjunction with wind, the likelihood of failure will increase further.
5. Trees are more susceptible to soil-related windthrow when the soil is saturated, particularly if they are shallow-rooted species or if the soil is limited in depth.
6. Interior forest trees that have become abruptly exposed may have limited capacity to tolerate increased loading until response growth has taken place.

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Tree Biology and Mechanics

Module 5

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Tree Biology and Mechanics

Module 5, Part 1: Wood Structure

Learning Objectives

- Describe the key components of wood structure, including cellulose and lignin, and discuss how each functions in tree stability.
- Explain how trees in good health respond to the loads they experience by producing new wood that varies in amount, placement, and characteristics.
- Discuss how tree maturity and lifespan can affect tree structure and health.
- Discuss common response growth adaptations and how they may affect likelihood of failure (e.g., reaction wood, flexure wood, woundwood).
- Explain why an overall assessment of tree health is an important component of risk assessment.

Key Terms

angiosperm	flexure wood	phloem	tension wood
buttress roots	growth rings	ram's horn	tracheid
cambium	gymnosperm	rays	trunk taper
cellulose	heartwood	reaction wood	vascular cambium
compression wood	latewood	response growth	vessel
diffuse porous	lignin	ring porous	woundwood
earlywood	mechanical stress	sapwood	xylem
fiber	parenchyma	strain	

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Introduction

After considering the targets and the site, it is time to take a closer look at the tree. This module discusses the fundamentals of tree structure and health, decay, and mechanics that are important for arborists to know prior to undertaking a tree risk assessment.

A tree risk assessor should have a fundamental understanding of tree biology. The purpose of this module is not to provide a comprehensive text on the topic but rather to review how the anatomy and physiology of a tree affect the likelihood of failure. A tree's structure and response mechanisms are part of a complex interaction between the tree and its environment, including the loads experienced and the effects of wood decay. Understanding wood structure is a prerequisite for understanding decay and response growth.

Wood Structure

The way wood develops has a direct influence on how trees react to external forces, decay, and other stresses. Every year, a tree allocates some of its energy to producing new leaves and new wood. The basic water-conducting system in the wood of a tree consists of groups of cells joined together like pipes. In **gymnosperms** (mainly conifers), these pipes consist of **tracheids**, while in **angiosperms**, they consist primarily of **vessels**. Gymnosperm wood does not contain vessels.

Tracheids and vessels are combined with **fibers** and living **parenchyma** cells to comprise the **xylem**, or wood. Wood is the main source of load-bearing capacity in the branches, trunk, and roots.

The key load-bearing components in xylem cell walls are cellulose and lignin. **Cellulose** is whitish in color, flexible, and provides load-bearing capacity when under tension. Cellulose is surrounded by a matrix of cell-wall material, including **lignin**. The brownish lignin provides stiffness and load-bearing capacity in compression. Together, cellulose and lignin make wood flexible and strong.

Phloem is not a structural tissue. It is formed by the cambium and is located between the **cambium** and the bark. It serves to transport carbohydrates from leaves to branches and down the trunk to other parts of the tree. Both xylem and phloem can change in reaction to physical, physiological, and chemical stresses.

Definitions of Some Key Terms

Several key terms are required for understanding tree biology and wood structure. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

cellulose—complex carbohydrate found in the cellular walls of the majority of plants, algae, and certain fungi.

compression wood—reaction wood in gymnosperms, and some angiosperms, that develops on the underside of branches or leaning trunks and is important in load bearing.

flexure wood—response growth triggered by the continued flexing of a tree stem or branch.

lignin—organic substance that impregnates certain cell walls to thicken and strengthen the cell to reduce susceptibility to decay and pest damage.

reaction wood—wood formed in leaning or crooked stems or on lower or upper sides of branches as a means of counteracting the effects of gravity.

tension wood—form of reaction wood in angiosperms (e.g., hardwoods) that forms on the upper side of branches or the trunks of leaning trees.

woundwood—lignified, differentiated tissues produced on woody plants as a response to wounding.

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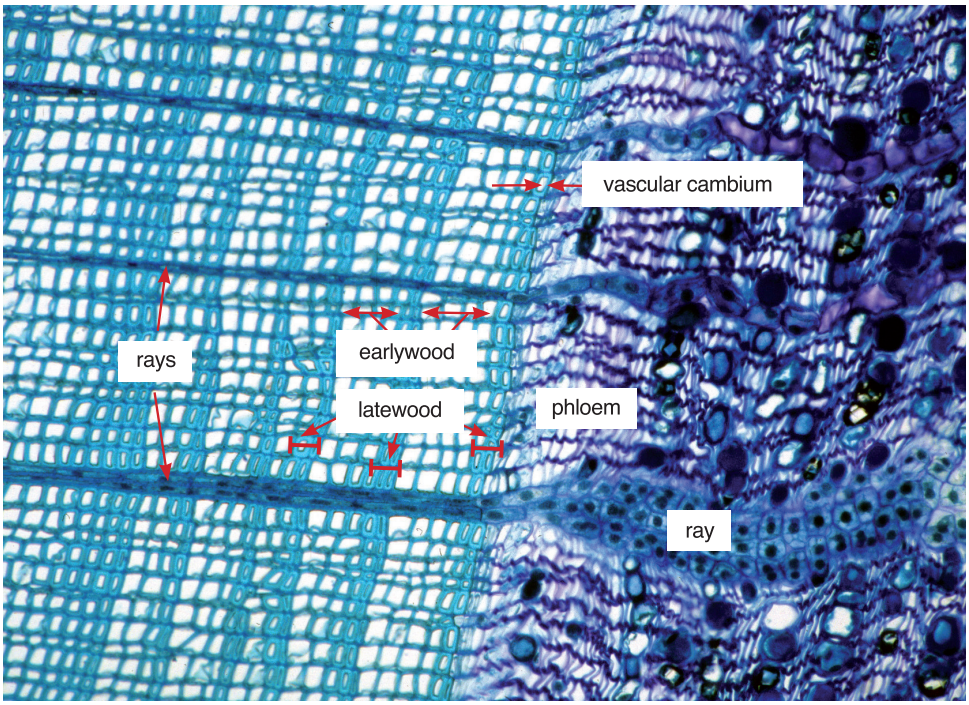

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Figure 5.1 Wood is the main source of load-bearing capacity in the branches, trunk, and roots. This cross section of a conifer stem shows xylem on the inside, the vascular cambium, and phloem and bark on the outside.

Specialized parenchyma cells that develop radially across the xylem and phloem are known as **rays**. Think of the arrangement of rays as similar to spokes on a wheel. Rays transport nutrients and other materials radially through the sapwood of the roots, trunk, and branches to and from the phloem. They store energy (starch), perform an important mechanical function by binding consecutive annual **growth rings** together, and help the tree minimize bending stresses. They also make up part of a tree's defense mechanism by physically and chemically resisting the spread of internal decay.

New wood formation occurs annually in temperate climates and nearly continuously in tropical and subtropical areas. In temperate climates, new wood is normally added as a distinct annual growth ring, reflecting a clearly defined growing season followed by a period of dormancy. In tropical and subtropical areas, where a period of dormancy may be absent, or occur multiple times during one year based on soil moisture levels, there can be more than one growth period in one year.

Growth rings often have two distinct wood forms. New wood produced at the beginning of the growing season typically has thin cell walls and larger-diameter vessels and tracheids. This is called **earlywood**. Later in the season, new cells are produced with thicker cell walls and the vessels and tracheids are smaller in diameter. This is called **latewood**. The latewood component is the stronger part of each growth ring. These wood characteristics are affected by tree species, rate of growth, and site conditions.

Earlywood and latewood cells are arranged into two distinct wood patterns in angiosperms, **ring porous** and **diffuse porous**, depending on the tree species. Vessels in cross section are called pores. Ring porous species, such as northern red oak (*Quercus rubra*) and white ash (*Fraxinus americana*), have a distinct earlywood compared to the latewood. The pores are larger in diameter in the earlywood and smaller in diameter in the latewood. Diffuse porous species, such as paper birch (*Betula papyrifera*) and rain tree (*Samanea saman*), have no distinct size difference between the earlywood and latewood cells.

The cross section of a mature root, trunk, or branch includes sapwood just inside the bark. **Sapwood** contains some living cells and is active in transport of water and dissolved minerals, and storage. In the center, the wood contains no living cells, may be darker in color than the sapwood, and is often referred to as **heartwood**.

Most of this anatomy and physiology applies only to dicotyledonous trees and gymnosperms with **vascular cambium**.

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Monocotyledonous trees—such as palms, yuccas, and bamboos—do not have vascular cambium and do not produce annual rings. Instead, they develop bundles of vascular tissue throughout the stem, each one containing xylem and phloem. In general, the strength of their stems is derived mainly from the lignin content in the tracheids and cellulose fibers within each bundle.

Growth Strategies

Tree growth is influenced by genetics and environmental conditions. Young, healthy trees typically grow rapidly in height, crown spread, and stem diameter. As they enter maturity, the rate of growth slows, and eventually overall health starts to decline due to environmental stress or pests. New wood is still being added, but growth rings become narrower than when the tree was younger.

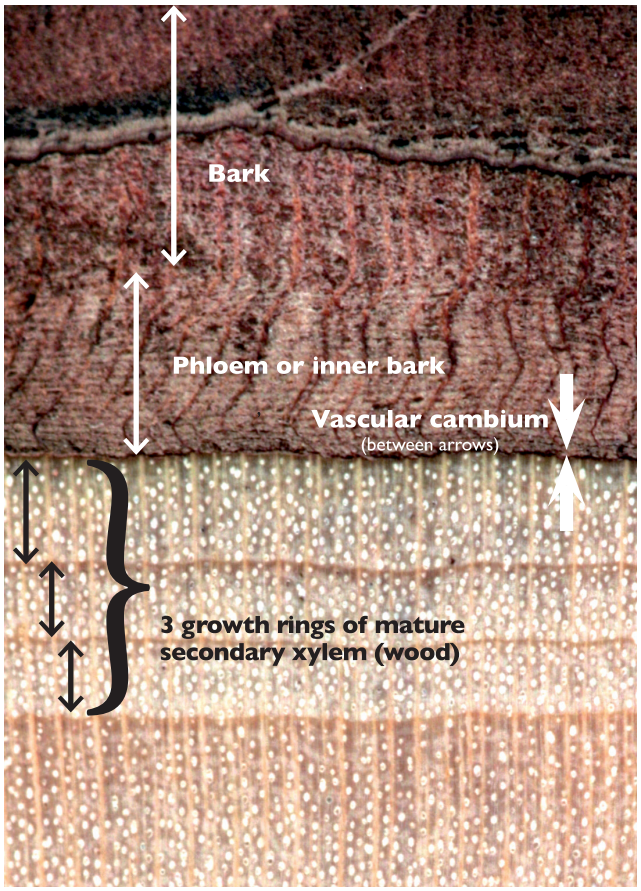

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Figure 5.2 In temperate climates, new wood is normally added as a distinct annual ring, reflecting a clearly defined growing season followed by a period of dormancy.

Some species of trees live many hundreds of years, while other species are short lived, perhaps only 40 to 50 years.

Long-lived species usually use more of their resources towards defense to overcome the effects of pests and environmental stress. Short-lived species usually use their resources to prioritize new growth rather than defense and often have less ability to compartmentalize damage and decay.

If a tree is not able to sustain growth, tree parts will begin to die. Although branches at the top of the tree may die, growth rings are still produced lower down in the tree, increasing the diameter of the trunk area. This process may add stability because the crown size is reduced and the trunk diameter increased.

Healthy trees have reserves of stored energy, which allow them to respond to pests and environmental stress. Unhealthy trees have less ability to respond. Ultimately, trees reach a point where they are unable to respond and adapt to biological and environmental stresses, and they die.

Knowing the tree's typical life span and life strategy can be important when assessing tree structure and health. This information may be useful in understanding responses to decay or other stress factors.

Response (Adaptive) Growth

Response growth is new wood produced in response to damage or loads which compensates for higher **strain** (deformation due to **mechanical stress**); it

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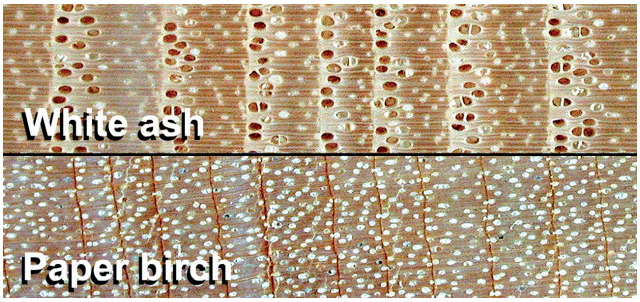

Figure 5.3 White ash (*Fraxinus americana*, top) is ring porous, and paper birch (*Betula papyrifera*, bottom) is diffuse porous.

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includes reaction wood (compression wood and tension wood), flexure wood, and woundwood. The amount of new wood that a tree produces depends on species, health, energy reserves, and available resources (e.g., water, light, nutrients). Distribution of new wood is determined in large part by mechanical stress, but it is also governed by physiological and morphological conditions. The newest layer of wood experiences the greatest bending and torsional stresses. As a consequence, new wood cells experience greater compressive and tensile strains in bending than cells closer to the pith. Repeated strains experienced by cells in the vascular cambium influence the number and orientation of new wood cells and their material properties.

Tree Health vs. Structural Stability

Tree health and stability are related but not the same. For example, a healthy tree can have significant heartwood decay and be subject to loads that may result in structural failure. In another case, an unhealthy tree may not have decay, and the thin crown may have less wind resistance. So, in comparison, the healthy tree in this example may be more prone to failure than the declining tree.

Healthy trees have enough carbohydrate reserves to meet the many demands needed to stay biologically vigorous and structurally sound. Tree health can be affected by many issues including pests and environmental conditions, especially if the trees are not adapted to the site.

As tree health declines the carbohydrate reserves may be reduced or depleted. As a result, there may be less energy available to resist the spread of decay or to produce the response growth needed to offset strength loss caused by decay. Tree stability may be compromised as load-bearing components of the tree are weakened over time. This may increase the likelihood of failure.

Dieback in the crown of a tree may or may not be related to changes in tree stability. The structural condition of a tree and possible causes of the dieback should be examined and assessed even if the tree appears healthy.

Reaction Wood

Reaction wood is wood produced in branches and leaning trunks in response to gravity. Compression and tension wood are the two types of reaction wood that are anatomically unique and act mechanically to compensate for stem lean or branch sagging.

Compression wood, which is found in gymnosperms and some angiosperms, exerts compressive forces on the lower side of a stem or branch. It is composed of cells that expand longitudinally as they mature. Compression wood has thicker cell walls that contain less cellulose and more lignin. The annual rings have a higher percentage of latewood than in noncompression wood. This latewood is often darker in color. By expanding longitudinally, compression wood growth forces or pushes the trunk or branch upward, resisting the force of gravity.

Tension wood, which is found in angiosperms, exerts tensile forces on the upper side of a stem or branch. As they develop, cells in tension wood contract. This contraction acts to pull the trunk back toward vertical or hold the branch up against gravity. Tension wood has smaller-diameter, thick-walled cells with more cellulose and less lignin in the matrix between the cells. Angiosperms predominantly produce tension wood; however, some may also respond to static loads by producing additional growth in the area of compression. Conifers are not known to form tension wood.

When a branch is cut and viewed in cross section, thicker growth rings are often seen on one side of the branch (lower side for compression wood), especially near where the branch is attached. A similar pattern may be found on the lower trunk of a leaning tree, where reaction wood forms on one side to keep the tree trunk vertical.

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Response Growth Properties

Properties that show the potential for, or presence of, response growth:

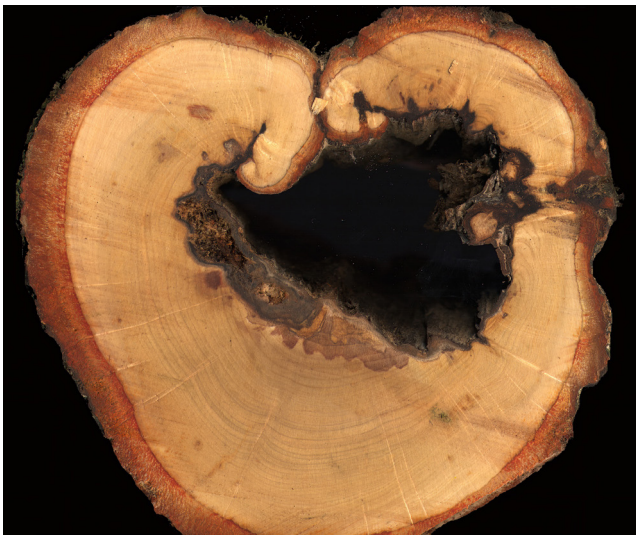
- Crown—healthy, vigorous, good foliar color, good twig growth, and few pests
- Bark—healthy and intact
- Woundwood—well developed around cuts, cracks, and/or openings
- Wood growth—local increases, such as ribs and bulges, near a structural defect; enlargement in diameter of areas weakened by internal decay
- Root flare—wide flare or buttress roots
- Trunk lean—visibly corrected

Flexure Wood

Some response growth development occurs in areas of the tree that are affected by movement caused by changing loads. Termed **flexure wood**, it is formed in stems and branches in response to wind loading. It is anatomically similar in some respects to tension wood. The development of branch and **trunk taper** and **buttress roots** are examples of load-responsive (flexure) growth.

Woundwood

Woundwood is produced in response to cambial damage. Woundwood is typically stronger, denser, and chemically different from other wood, and it resists decay better than normal wood. A cavity in a stem increases stress. If enough woundwood has formed, its greater strength may compensate for the load increase on the reduced cross-sectional area. If a wound or cavity is not readily closed due to the size of the opening or other factors, woundwood may enlarge or curl inward at the edge of the cavity (a feature commonly called a "**ram's horn**"). Ram's horns form when the lack of supporting wood, caused by cavities or cracks, causes woundwood to curl into the opening as well as laterally in an attempt to close the wound. A ram's horn formation can add wood, which increases the stem's load-bearing capacity at the opening. The rate of woundwood development depends in part on tree health and species.



Julian A. Dunster

Figure 5.4 Ram's horns form when woundwood grows into the void caused by damage that leads to cavities or cracks.

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Figure 5.5 This spruce (*Picea* sp.) was bent by snow in approximately its 13th year. The compression wood (right) developed over several years as the tree righted itself. The difference in color can be attributed, in part, to differences in cell wall composition.

Safety Factor

Trees develop more wood or stronger wood in some parts of the tree than is needed to support the tree under normal load conditions; this can be thought of as a safety factor. The magnitude of the safety factor can vary significantly within the tree and as a tree ages. This overdevelopment helps to support

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Figure 5.6 Woundwood is developing around this decaying wound. If the tree remains vigorous, the wound may eventually close completely. Note the zone lines of decay progression and reaction zones.

the tree under extraordinary loads of strong winds, snow, or ice.

Tree risk assessors should look for and assess the significance of response growth when assessing the likelihood of failure. Areas of increased growth should be interpreted as indications of the tree's response to a structural weakness, stimulus, or repeated movement. Tree health is an important factor for predicting the tree's capability to compensate for a loss in load-bearing capacity due to defects.

Interpretation of Response Growth

The newest layers of wood experience the greatest torsional, compressive, and tension stress, which is explained in more detail later in this module. As a consequence, the compression or extension of new wood cells under bending loads is greater than the deformation experienced by other cells. The repeated deformation of cambium cells influences the number and orientation of new wood cells and their material properties. In general, cells respond to tension and compression by adding varying amounts of lignin or cellulose. New wood that is continually stretched during development will have higher amounts of cellulose present, while new wood primarily under compression will have more lignin.

Response growth may appear as areas of enlarged wood growth such as bulges, ridges, or fused buttress roots in response to a large load, structural weakness, decay, repeated movement, or other stimuli. Near cracks, external indicators of response growth include spiraling or straight ribs. Response growth shows both the need for and the ability to produce new growth that compensates for increased structural stress. The amount of new wood a tree produces depends on species, health, energy reserves, and available resources (i.e., water, light, nutrients).

When response growth is recognized, the tree risk assessor should try to determine its cause and evaluate its effect on the likelihood of failure within the defined time frame. Trees can adapt to weaknesses and remain upright for many decades if sufficient structural compensation occurs.

E. Thomas Smiley

Figure 5.7 This tree has an enlarged area at the base of the trunk. Areas of increased growth such as this should be interpreted as indications of the tree's response to a structural weakness, decay, repeated movement, or other stimuli.

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CASE STUDY

Interpreting Observations

Assignment: The manager of a city park contracted a Level 2 assessment of selected trees in the early spring prior to the high-use season. This bigleaf maple (*Acer macrophyllum*) was identified for assessment.

Time frame: One year.

Targets and Site: The main targets at this site are people using the park throughout the year during daylight hours, with high levels of use in the summer season. The overall occupancy rate was categorized as *occasional* during the time frame.

The tree is protected from wind by other trees in the park. There were no visible stumps or other indicators of tree failure/removal at the site.

Tree Conditions: The tree is healthy with good growth, twig extension, and foliar density. The maple has two large codominant stems with a swelling below the union that has split. The vertical line with light brown growth at the edge of the split was identified as woundwood. This indicates that the split oc-

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curred at least one growing season prior to the assessment. The width of the woundwood (about 0.5 in [12 mm]) suggests a vigorous response.

Inspection of the exposed wood within the split identified a slightly discolored (gray) surface to the wood, and there is no evidence of further splitting since the original crack formed.

Striking the tree near the split with a mallet produced a hollow sound. This indicated that decay is likely to be associated with the split.

An 18 in (45 cm) long probe was completely inserted into the split, finding no direct connection between the two codominant stems.

Analysis: The likelihood of failure was categorized as *probable* for the one-year time frame. The likelihood of impact for people was categorized as *very low*. The combined likelihood of failure and impact (from Matrix 1) was *unlikely*. Consequences were rated as *severe* for people, making the risk *low* (Matrix 2).

Mitigation Options:

1. Restrict access to the area.
2. Install a structural support system of a cable and brace rods.
3. Remove the tree.
4. Retain and reassess in one year.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

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Strong response growth indicators imply that the tree has substantial stored energy reserves to maintain biological health and mechanical stability. Poor response growth may suggest that the tree is physiologically weak. For example, an unhealthy tree is less able to compartmentalize decay or grow new wood to bear an increased load. Lack of response growth could also indicate that the decay or wound is recent or has not significantly reduced load-bearing capacity. Again, tree health is an important factor in predicting the tree's ability to compensate for increased mechanical stress due to decay or increased loads and may impact assessment of likelihood of failure. Currently, however, there are few guidelines for evaluating the effectiveness of response growth to compensate for structural defects.

Tree Health and Vigor

The ability of a tree to resist the spread of decay and to produce sufficient wood growth to maintain stability is greatly dependent on tree health and vigor. There are several indicators of tree health, including twig elongation, overall foliage density (if present), foliage size, chlorosis, and necrotic foliage. Dieback of small twigs from the top down is often a symptom of poor root function, possibly due to root damage, decay, disease, or drought stress. Insect pests, diseases, and disorders that are unrelated to tree structure may still have relevance because they may diminish the ability of a tree to respond to structural issues.

E. Thomas Smiley

Figure 5.8 Several indicators are used to assess tree health, including overall tree growth, twig extension, and foliage density. Abnormally sparse foliage can be an indicator of stress or decline.

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Summary

A tree risk assessor should understand tree structure and defense mechanisms to synthesize the data collected and to assess the likelihood of failure. Knowledge of wood structure is key to understanding tree decay and response growth. A tree's ability to defend against the spread of decay and to produce sufficient wood growth to maintain stability is greatly dependent on tree health and vigor.

Key Concepts

1. A tree's structure and response mechanisms are part of an elaborate interaction between the tree and its environment, which includes the loads experienced and the effects of decay.
2. The key load-bearing components in wood cells are cellulose and lignin. Cellulose provides flexibility and strength when under tension. Lignin provides stiffness and compression-bearing capability. Together, cellulose and lignin make wood strong yet flexible.
3. Response growth is the production of new wood in response to damage or loads to compensate for higher movement or load at the cambium; it includes reaction wood, flexure wood, and woundwood. Distribution of new wood is determined in large part by mechanical stress, but it is also influenced by tree health.
4. A tree's ability to defend against the spread of decay and to produce sufficient wood growth to maintain stability is greatly dependent on species, general health, and vigor.

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Tree Biology and Mechanics

Module 5, Part 2: Decay

Learning Objectives

- Describe the CODIT concept and how it slows the spread of decay.
- Explain how the decay modes of white rots, brown rots, and soft rots differ and the implications of each mode on tree stability.
- List examples of definite and potential indicators of decay.
- Explain how understanding decay modes and the tree parts affected can be used to help assess the likelihood of failure.

Key Terms

advanced decay	column of decay	heartwood	saprophyte
barrier zone	compartmentalization	heartwood rot	sapwood
basal rot	conk	incipient decay	sapwood rot
basal swelling	decay fungi	intermediate decay	soft rot
bracket	decomposition	pathogen	suberin
brown rot	definite indicator	potential indicator	white rot
canker rot	discoloration	reaction zone	wood decay
cavity	fungal fruiting structure	rhizomorph	woundwood
CODIT		root rot	

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Introduction

Wood **decay** is the process of wood degradation by microorganisms. Most wood decay is caused by fungi, although bacteria, other microorganisms, and chemical reactions associated with oxidation may also play a role. Identifying the presence of **decay fungi** and their implications is important for determining the likelihood of failure. There are thousands of tree decay fungi throughout the world. Within any one region there will be a relatively small number capable of impacting the structural components of living trees.

In many cases, loss of wood strength occurs long before there is any visible evidence of decay. Significant amounts of decay in load-bearing portions of the tree (i.e., branches, trunk, roots) reduce load-bearing capacity and increase failure potential. Risk assessors should know that decay is a very common problem in urban trees. Some decay fungi are of little consequence to tree stability; others can rapidly lead to failure. Healthy trees with good vigor defend against the spread of decay. If the tree lacks vigor or is stressed, the fungi may overcome the defenses and spread more rapidly.

Risk assessors should be familiar with the wood decay fungi common to their region and be able to recognize and understand the implications of fruiting bodies such as mushrooms and **conks (brackets)**. Using information appropriate to the region, an assessor should understand that decay type, amount, and location within the tree as well as tree species and geographic region affect the assessment. Assessors should also be aware that fungi are sometimes reclassified or renamed, so the same fungus may have different names depending on the reference sources. If unsure of identification, take photographs and seek assistance from professionals or laboratories that have access to microscopes or genetic (DNA or RNA) analysis.

Definitions of Some Key Terms

Several key terms are required for understanding response of trees to injury and wood decay. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

barrier zone—(CODIT Wall 4) chemical responses and anatomical features formed by the vascular cambium in response to wounding. It inhibits the spread of decay into xylem tissue formed after the time of wounding; strongest CODIT Wall.

brown rot—fungal wood rot characterized by the breakdown of cellulose.

compartmentalization—natural defense process in trees in response to wounding by which chemical barriers and physical features act to limit the spread of disease and decay organisms.

decay—process of wood degradation by microorganisms, primarily fungi.

pathogen—decay fungi that can breach barrier and/or reaction zones and decay healthy sapwood.

reaction zone—chemical responses in sapwood in reaction to wounding that limit the spread of decay.

saprophyte—decay fungi that cannot attack healthy sapwood and only obtains nutrients from dead matter.

white rot—fungal decay of wood in which lignin and in some cases cellulose are broken down.

Types of Decay Fungi

Wood decay fungi produce enzymes that break down wood components, which then provide nutrition to the fungi. Most decay fungi attack nonliving cells (**saprophytes**), but some attack living cells and cause tree disease (**pathogens**). Virtually all wood decay fungi can survive as saprophytes on dead

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The Davey Tree Expert Company

Figure 5.9 In general, root decay is difficult to detect and assess because its extent and severity cannot be easily observed during a basic assessment, and crowns may show few symptoms. With some fungal decay species, the only definite indication of decay is the presence of fruiting bodies, although their presence may be seasonal, and, in some instances, they may have been removed intentionally.

wood for a period of time. This is important because pathogenic decay organisms can remain viable in decaying wood or roots for long periods of time.

Many decay fungi infect trees through wounds. Dead or pruned branches, or any injury that penetrates through the cambium, are common entry points for many decay fungi. Some are able to attack only damaged **sapwood**; some attack only **heartwood**. **Canker rot** fungi may attack both sapwood and heartwood and also kill bark and cambium in the later stages of decay. High moisture levels may prevent or slow down decay because the enzymes involved in cell degradation require oxygen. Wood that is desiccated (dried out) may decay more rapidly.

Some fungi such as *Armillaria*, *Heterobasidion irregulare*, *Coniferiporia*, and *Phaelous schweinitzii* spread through root contact.

Decay fungi are often categorized as white rots, brown rots, or soft rots. Each group affects wood strength differently because each breaks down different cellular components. Some decay fungi exhibit the characteristics of more than one type of decay. This is further complicated by the fact that fungi are adaptable and sometimes can change their mode of decay, depending on their host species and the conditions present.

White Rots

White rots are by far the most common decay fungi. Initially they break down lignin, and, to various extents, cellulose and hemicellulose in cell walls, leaving spongy, sometimes stringy, saturated wood that often is white or yellowish in appearance.

Trees affected by white rot may develop new wood around the decayed area. As the wood becomes less stiff, the living cells adjacent to the decayed area may experience greater movement due to loading. This may lead to localized areas of enhanced production of wood that results in swelling (response growth) that may partially or fully compensate for the strength loss at that location. If the wood has been weakened to the point that compression results

Christopher J. Luley

Figure 5.10 White rots break down lignin primarily, and they also to various extents break down cellulose and hemicellulose in cell walls, leaving spongy, sometimes stringy, saturated wood that often is white or yellowish in appearance.

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in fiber buckling, horizontal ridges at the trunk flare may be observed in a visual assessment.

White rots are most commonly seen in hardwood trees, although a few species also affect conifers. Common white rot fungi associated with root decay include species such as *Armillaria* and *Ganoderma*.

Brown Rots

Brown rots primarily break down cellulose and hemicellulose but generally leave the lignin intact. The intermediate decay is brittle and crumbly and is typically brown in color. As the decay advances, the wood shrinks and cracks into blocks, leading to the term "cubical brown rot." Major loss of bending strength can occur early in the decay process. Because brown rots are more rigid, response growth tends to be less than in trees with white rot.

Brown rots primarily affect conifers, although there are important brown rots in hardwoods too. Examples of brown rot fungi include species of *Laetiporus* and *Phaeolus*.

Soft Rots

Soft rots typically decay cellulose first, but they may also modify hemicellulose and lignin, damaging cell walls. Soft rots create localized pockets of decayed wood that are softer than the surrounding nondecayed areas.

Christopher J. Luley

Figure 5.12 Soft rots create pockets of decayed wood.

Christopher J. Luley

Figure 5.11 Brown rots primarily break down cellulose and hemicellulose but generally leave the lignin intact. The intermediate decay is brittle and crumbly, and it is typically brown in color. As the decay advances, the wood shrinks and cracks into blocks, leading to the term "cubical brown rot." Most brown rots are found in conifers.

Soft rots primarily attack hardwood species. The most important example of a soft rot found in living trees is *Kretzschmaria deusta* (also known as *Ustulina deusta*). This fungus can attack healthy sapwood in some trees, leading to potentially serious structural problems. Fungi that cause soft rots typically form fruiting bodies that are much less conspicuous than those that cause brown and white rots.

Progression of Decay

Risk assessors try to determine the presence or absence of decay at the time of assessment. When decay is present, tree stability is not automatically compromised. It is useful to know but difficult to estimate the rate of decay spread within a tree. Key factors to consider are whether the decay is only in dead wood (saprophytic) or attacking live wood (pathogenic), how much decay is already present, if the tree's defense mechanisms have contained it, and whether there is sufficient wood present to compensate for wood lost. The overall health and vigor of the tree may be a useful indicator about how well the tree can deal with the decay.

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Decay progression is related to multiple factors:

- Tree and fungus species characteristics, as well as the interaction between the two
- Ability of the tree to compartmentalize decay
- Age and vigor of the tree at the time of injury
- Type of pathogen (strongly or weakly pathogenic)
- Whether additional wounds have occurred in other years that have damaged the barrier zone
- Regional and site moisture and temperature

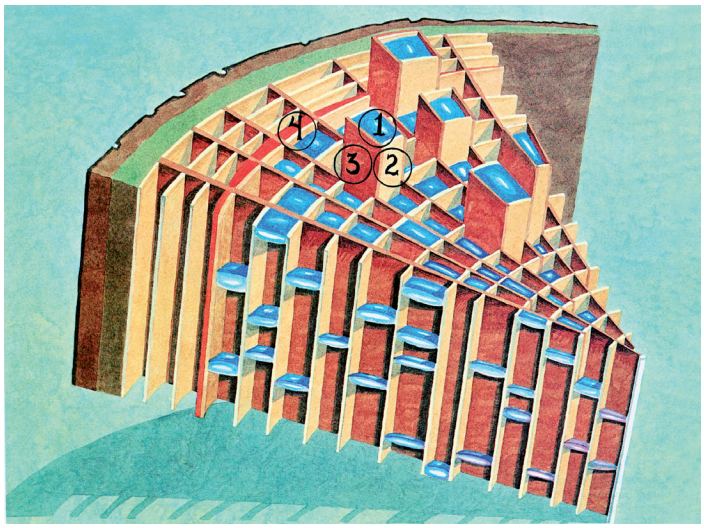

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Figure 5.13 This illustration is a graphical interpretation of the four conceptual CODIT walls.

After infection, wood goes through stages of **decomposition**. **Incipient decay** marks the initial stages where the fungus has invaded cells and is becoming established. Cell walls are starting to get thinner and lose some strength. This stage of decay can be detected by laboratory or microscopic analysis, but usually no obvious visible change has occurred. At the **intermediate decay** stage, wood **discoloration** becomes visible and wood strength is markedly reduced, but some cell structure is still present. Finally, **advanced decay** occurs, and all wood strength and cell structure are lost. By the time advanced decay is visible, the wood has already lost its strength and load-bearing capacity.

CODIT

The acronym **CODIT**, originally stated as Compartmentalization of Decay in Trees, has become more inclusive in its meaning. CODIT is now often described as Compartmentalization of Damage, Dysfunction, or Decay in Trees, to account for its more general reaction as a wound response. Trees react to wounding in a series of stages. After living xylem is damaged, the tissues around the wound become dry (desiccate) and no longer provide water transportation (they are dysfunctional). Over time, fungal and/or bacterial organisms may enter through the wounded area to infect the wood. The live wood responds to the damage and microbes in a relatively predictable manner as represented by the CODIT model.

Wounded trees do not heal damaged tissues in the way that animals do. Trees develop structures and chemical compounds that contain or isolate the effects of wounds and decay, and then the trees attempt to seal the wound. Changes take place in the existing live xylem, and new xylem develops around damaged areas as a means of isolating and limiting the progression of damage and decay. In this way, the tree maintains its biological and mechanical integrity. This response is termed compartmentalization. The purpose of **compartmentalization** is to contain or "wall off" the damaged and dysfunctional tissue and to stop or slow the advance of decay organisms before they move into healthy wood. The physiological and chemical responses occur in the living cells within the xylem (parenchyma) around the wounded area.

The CODIT model describes a system in which four conceptual "walls"—zones in the sapwood—develop to compartmentalize and limit the spread of decay. Each wall serves to prevent or slow decay progression in a certain direction. This simple model applies to most—but not all—trees and types of decay. Although the progression of decay can often be slowed or stopped, some pathogens may not be successfully compartmentalized.

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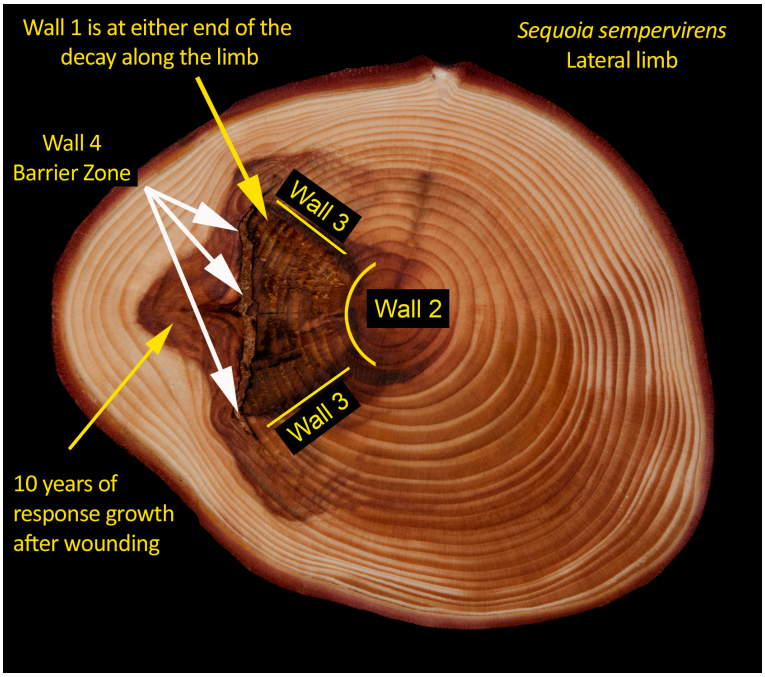
Wall 1 resists the spread of decay up or down woody stems, or along branches. Wall 1 produces materials that plug the xylem tracheid and xylem vessel cells. Wall 1 is the weakest of the four walls. It is common for separate decay columns that are developing above or below along the axis of a stem to coalesce when Wall 1 fails to stop decay progression.

Wall 2 resists the radial spread of decay towards the center of the tree. Composed of the latewood cells in each growth ring, Wall 2 is mostly continuous around the tree. This is typically the second-weakest wall.



Julian A. Dunster

Figure 5.14 CODIT walls limit the spread of decay.

Wall 3 resists the tangential spread of decay from spreading from the point of injury around the trunk. It is a series of lateral walls made up of the ray cells on either side of the injury. The living parenchyma cells in the rays create chemical changes that are toxic to decay microorganisms. This process involves production and accumulation of special decay-resistant compounds (phenolic compounds in angiosperms and terpenes in gymnosperms). Because of the pattern and distribution of ray cells in the xylem, Wall 3 consists of discontinuous, but overlapping, walls that establish a relatively strong defense.

The first three walls are composed of preexisting wood tissue that undergoes changes after injury to serve a defense function (the **reaction zone**). The initiation of physiological changes in wood at Walls 1, 2, and 3 is the first stage of compartmentalization. These walls will also reform if decay pathogens break through barrier zones or reaction zones when attacking living wood.

The second stage is the development of Wall 4 which is formed after the initial damage takes place.

Wall 4 is also called the **barrier zone** and is formed by the cambium. The new xylem that develops after wounding establishes an interface that prevents decay from moving outward by physically separating the old tissue from the new. Wall 4 is the strongest defense of the four walls against pathogens and decay. It is partially separated from preexisting wood because the new ray cells are not connected to the old ones in the area of the wound. Internal cracks (ring shakes) may develop at Wall 4, spreading around or up and down the tree.

The new cells of the barrier zone are both anatomically and chemically different from cells produced before wounding. The xylem parenchyma cells contain compounds that are toxic to microorganisms. The new cell walls also contain **suberin**, a waxy substance that protects the cambium and sapwood from drying out. Suberin also inhibits the spread of fungi into the new tissues. It is possible that sapwood with a high moisture content, maintained by the sealing of wood by suberin in the barrier zone, also inhibits invasion of sapwood by aerobic fungi.

Decay does not spread beyond the wood present at the time of wounding if there is a strong Wall 4 (barrier zone) response. The wood that develops after the damage will be protected from the outward spread of decay infection by the barrier zone and is, therefore, typically free of decay. This wood is known as **woundwood** and is an indicator that a positive response to wounding by the tree has

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Figure 5.15 This tree has completely compartmentalized the decay from an old pruning wound. The barrier zone and the reaction zone are clearly visible. From the exterior, the contained wood is seen as a swelling on the trunk.

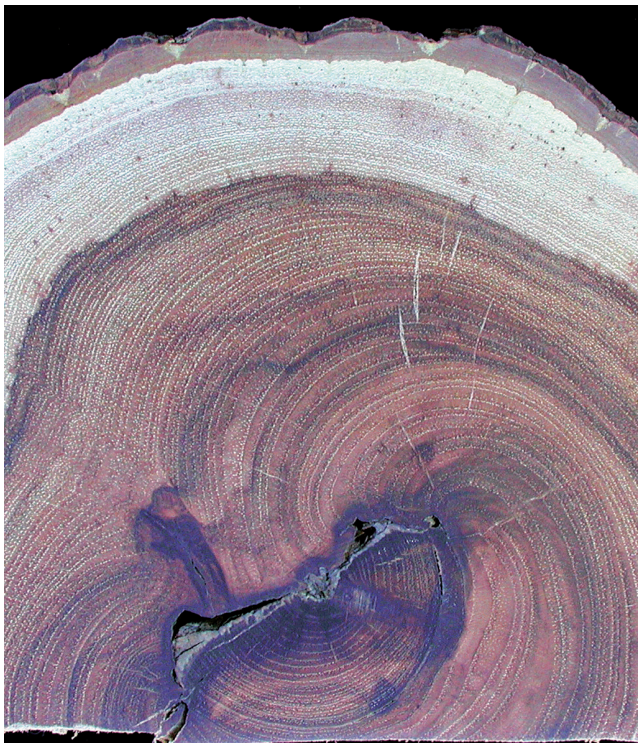

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Figure 5.16 As the tree compartmentalized this wound, woundwood ribs formed, and, eventually, the vascular cambium was reconnected. New wood completely compartmentalized the wound.

occurred. As a result, the vascular cambium may remain intact and continue to develop outward, away from the decayed areas. The newer, decay-free wood forms a shell of nondecayed wood around the decay column and plays an important role in mechanically supporting the tree.

Wall 4 requires energy to maintain its defensive abilities. Physiologically stressed trees may be unable to maintain Wall 4, in which case additional areas of decay can spread outward from the original point of injury.

A tree's ability to effectively compartmentalize decay is an important factor in assessing possible loss of wood strength and likelihood of failure. It is fairly common for Walls 1, 2, and 3 to be only partially successful, allowing decay to spread inside the tree, forming a **column of decay** and, eventually, a **cavity**.

How well a tree compartmentalizes decay is affected by genetics, age, health, stress, seasonal timing of injury, virulence of the decay organisms, and the growing environment. Aggressive pathogens can even breach Wall 4, especially if the tree is physiologically stressed. If the barrier zone fails to stop the fungal progression, decay will progress outward towards the bark. The size of the wound will also affect the response of the tree. A large wound that extends deep into the sapwood will require a larger investment of energy by the tree to contain the decay than would a small or shallow wound. If the wound extends into the heartwood (dead xylem), there is no CODIT response possible, and potential for decay infection is greater.

Tree species vary in their ability to compartmentalize decay, and some tree–fungus interaction studies have been published on this topic. Species failure profiles can be a good source of information on decay spread within a species for a given region. Regional guidelines may be available for compartmentalization capabilities of tree species. In general,

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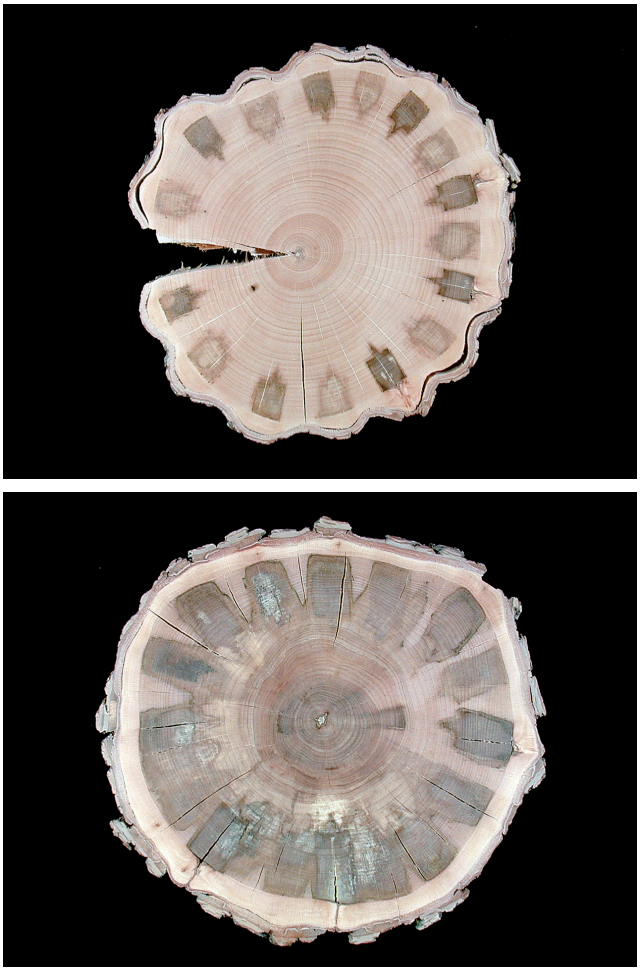

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Figure 5.17 Strong and weak compartmentalization. The tree on the top has effectively compartmentalized the holes made for a research project. The tree on the bottom has not been as effective in limiting the spread of decay or discoloration.

fast-growing, short-lived hardwoods, such as many species of *Populus*, tend to be poor at compartmentalizing and may decay rapidly, while longer-lived hardwoods, such as many species of *Quercus*, are usually much better at compartmentalizing. Very resinous conifers, such as species of *Pinus* and *Larix*, are generally strong compartmentalizers and tend to decay more slowly.

Trees allocate resources for functions such as growth, defense, and reproduction. CODIT responses require energy and this involves reallocating carbohydrates away from normal leaf, branch, trunk and root development. Wounding a young, healthy tree will produce different responses than wounding an old tree that is physiologically stressed. Healthy trees may have surplus energy available to create strong compartmentalization responses. The same wound in a low-vigor tree may allow more rapid spread of the decay fungus because the tree may have less available energy to deal with the injury. The allocation of energy toward defense may reduce growth, leading to further loss of energy reserves in later years and, eventually, a more rapid spread of decay.

Location in the Tree

Decay can be classified by its location in the tree, such as root rots, **basal rots** (butt rots), heartwood rots, and sapwood rots. These classifications are not always distinct, as some decay may overlap different parts of the tree or move from one part into another.

Root Rots and Basal Rots

Root decay fungi (**root rot**) can infect roots several ways, most often through wounds. A few species enter as a result of root grafting between infected and uninfected trees, or with specialized structures called **rhizomorphs**. Rhizomorphs look like small-diameter shoestrings or dark-colored roots and are partially responsible for the spread of *Armillaria* species in soil or along roots. Rhizomorphs can directly infect buried root collars or susceptible roots on stressed trees. Root rots are also spread by waterborne or airborne spores.

Most root decay fungi infect through wounds in small-diameter roots, especially those stressed by lack of oxygen due to excessive moisture levels or by lack of water. In the urban environment, damage to larger-diameter roots from trenching, cultivation, or excavation can allow the entry of root decay fungi.

Many root decay fungi that grow in root heartwood can continue growing into the heartwood at the base of the trunk, and over time may enter the sapwood. This type of decay is referred to as basal (butt) rot. If basal rot is detected in a tree, root decay should also be suspected. Basal decay may also be associated with decay that entered through wounds in the lower trunk or root collar area.

Because some root rot fungi kill smaller-diameter roots, water absorption and translocation can be

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affected. This can create water stress, which may result in symptoms of dieback or thinning in the crown. These symptoms, however, may also be a response to other root-related problems. Not all root rots produce crown dieback symptoms and not all crown dieback is due to root decay. Root decay related crown dieback symptoms are not easy to distinguish from drought stress, root cuts, or other pest issues.

E. Thomas Smiley

Figure 5.18 Root decay fungi can infect roots in several ways, most often through wounds. Many root decay fungi will continue growing into the base of the trunk.

E. Thomas Smiley

Figure 5.19 This tree has extensive basal rot, but it is also exhibiting significant response growth.

In general, root rots are difficult to detect and assess because their extent and severity cannot easily be seen during a basic assessment. Many root rots result in structural root failure or windthrow. With some fungal decay species, the only definite indicator of decay is the presence of fruiting bodies, although their presence may be seasonal, or, in some instances, such fruiting bodies may have been intentionally removed. Other definite indicators include cavities in the tree.

Basal swelling and fused roots are potential indicators of root decay, possibly as a result of response wood produced through CODIT. When decay affects water uptake, indications may include crown dieback or other symptoms of loss of vigor (e.g., reduced growth, small leaves, yellow leaves).

Trees can also develop adventitious root systems after woody, structural roots are decayed or removed. These secondary roots can support tree health through water and nutrient uptake that may make the presence of root decay less obvious. Unless adventitious roots become large, they typically do not provide significant structural support.

Heartwood Rots

Heartwood rot (heart rot) is the term used to describe decay in the heartwood (center) of the trunk or branch. Although not all tree species have true heartwood, the term is generally applied in reference to decay of the center of any tree stem or branch.

Doug Sharp

Figure 5.20 Heartwood rot is often irregular in shape and frequently occurs in one or more columns within the tree.

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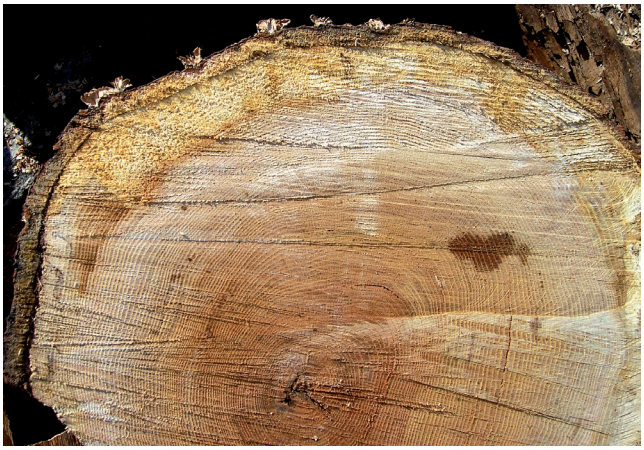
Rates of decay in heartwood are variable, based on tree species, condition, and aggressiveness of the decay fungus. Some fungi can only decay heartwood.

Christopher J. Luley

Figure 5.22 A definite indicator of sapwood rot is the presence of fungal fruiting bodies.

When looking at a tree's cross section or an increment core, distinguishing between heartwood and wood discolored due to decay can be important. True heartwood is present in many trees and is initiated by aging. As trees grow in diameter, the xylem in the center of the tree will become dysfunctional, and in many cases this transformation results in oxidation and the production of antimicrobial chemicals. Heartwood is under strong genetic control, starting in the oldest tissue and developing outward in newer tissue every year. Usually, it is continuous throughout the tree, circular in cross section, and found in larger roots and branches. In some species the heartwood is a different color from the sapwood. Wound-induced discoloration of wood is associated with tissue that has been exposed to air, bacteria, and fungi. It is seen as one or more columns in the tree's structure and is often irregular in extent across the section as well as up or down the tree. Tree risk assessors should not confuse natural heartwood with changes induced by wounding.



Christopher J. Luley

Figure 5.21 Loss of outer wood is considered more important to stem strength than internal decay. Outer xylem tissue contributes significantly more than internal wood to stem strength.

Sapwood Rots

Sapwood rot (sap rot) is initially limited to the sapwood in living or dead trees. Loss of sapwood due to decay, disease, or mechanical damage can contribute to tree failure. Because the outer xylem tissue (sapwood) is the critical component of stem strength, significant sapwood decay is often more important than loss of heartwood. A definite indicator of sapwood rot is the presence of small, numerous fungal fruiting bodies on the trunk or branches. The extent and rate of decay can be variable and will depend on tree species, site conditions, tree health, and the fungus. Sapwood decay in branches can develop relatively quickly and should be investigated carefully, especially on species that do not form heartwood.

Indicators of Decay

Decay is often a hidden defect associated with tree failures. Determining the presence, location, and extent of decay is important to categorize the likelihood of tree failure. A tree may appear to be solid and structurally sound, with a dense, healthy crown yet contains significant decay. **Definite indicators** of decay or missing wood occur only when decay is present.

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Christopher J. Luley

Figure 5.23 *Laetiporus* sp.

E. Thomas Smiley

Figure 5.24 *Ganoderma* sp.

USDA Forest Service Northeastern Area Archive

Figure 5.25 *Armillaria* sp.

The most common definite indicators of decay or internal voids include:

- Cavity openings; insect, bird, or other animal nesting holes; and other voids or openings to the outside of the tree.
- **Fungal fruiting structures**, such as mushrooms, conks, or brackets, that are attached to the tree, or mycelial fans under the bark.
- Carpenter ants, bees, termites, and other insects inhabiting or emerging from cavity openings.

Fungal fruiting bodies may not always be present or persistent. Some appear for days or weeks when moisture and temperature conditions favor development, while others are perennial and can persist on trees for many years. In addition, some fruiting bodies are inconspicuous. When they are present and visible, however, they can provide information on the location, and type of decay, but not necessarily the extent of the decay.

Nelda Matheny

Figure 5.26 Holes used by wildlife may be small on the outside of the tree but can indicate larger cavities within.

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Cavities in trees are open or closed hollow areas associated with decay. Cavities are definite indicators and may indicate more extensive internal decay than can be seen.

Cavity-nesting birds, bats, and insects are also definite indicators of decay. Birds will build their nests in hollows or dig out decayed wood to create a hollow. Honeybees often build hives in tree cavities.

Sharon Lilly

Figure 5.27 Carpenter ants are considered a definite indicator of decay because they nest in decayed wood.

Carpenter ants often nest in decayed wood. When present, they are mostly inside the tree except when foraging, so it is more common to detect carpenter ants by the presence of sawdust at the base of a tree or near the nest opening. On some thick-barked trees, some ants may live in the bark and thus are not indicators of decay.

Potential indicators may or may not be related to the presence of decay but may warrant closer inspection to be sure. The most common potential indicators of decay, strength loss, or missing wood include:

- The presence of old wounds or branch stubs that may have allowed decay fungi to enter the tree
- Response growth patterns, such as swelling, bulges, or ridges on a trunk or branch
- Cracks or seams
- Oozing through the bark
- Dead or loosely attached bark, or bark with abnormal patterns or colors
- Sunken areas in the bark
- Termite trails (mud tubes)

Nelda Matheny

Figure 5.28 Bleeding or oozing from wounds is a potential indicator of decay. Not all oozing is associated with decay.

E. Thomas Smiley

Figure 5.29 Enlarged growth is often from response wood, which is a potential indicator of decay.

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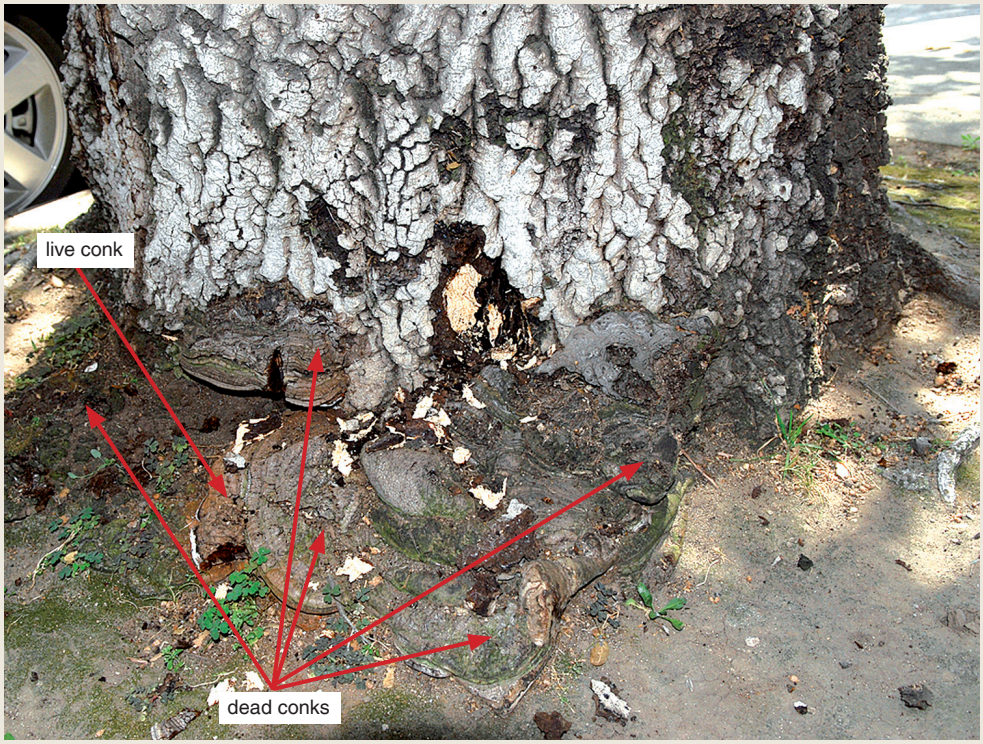
CASE STUDY



Sounding and Probing to Assess Decay

Assignment: A local resident requested a risk assessment of a large, 30 in (76 cm) diameter coast live oak (*Quercus agrifolia*) growing in a planting strip between the sidewalk and the street.

Time frame: Three years.

Targets and Site: Targets include pedestrians (*rare* occupancy), vehicular traffic (*occasional* occupancy), and parked cars (*constant* occupancy). Houses are not located within the target zone.

Tree Conditions: Several dead and decomposing *Ganoderma* conks are found on two sides of the base of the tree. There is a small cavity between the conks at the trunk flare. No signs of crown dieback are present nor are there any other obvious defects in the tree.

Striking the base of the tree with a mallet revealed many areas of the trunk that sounded dull or hollow. Probing the cavity close to a live conk revealed an area of decay, extending at least 20 in (51 cm) into the trunk. The wood extracted was white, soft, spongy, and very flexible. Careful examination of the bark on the other side close to the area of dead conks revealed similar wood conditions. Decay was extensive, and because it was located at the base, loading was significant.

Analysis: Likelihood of failure was categorized as *probable* for whole tree failure at the base of the trunk. Likelihood of impact for the parked cars was *high* but was *very low* for both pedestrians and traffic. The likelihood of failure and impact for the parked cars was *likely*, and it was *unlikely* for the people and traffic. The consequences of failure were *significant* for cars and *severe* for people. The risk was categorized as *high* for the parked cars and *low* for people and traffic.

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Mitigation Options: Remove the tree.

Residual Risk: None

The city arborist (tree risk manager) had the tree removed.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photo by Julian A. Dunster

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Summary

Wood decay is the process of wood degradation by microorganisms, primarily fungi. The presence of a large proportion of decayed wood may reduce the structural strength of a tree. Wounding initiates responses summarized by the CODIT model of compartmentalization. Understanding and evaluating the presence and extent of decay and its implications is important for determining the likelihood of tree failure within the defined time frame. Because a tree can appear healthy even when there is significant decay inside, it is important to recognize common definite and potential indicators of decay.

Key Concepts

1. The majority of wood decay is caused by fungi. There are thousands of wood decay fungi throughout the world, but only a relatively small number attack live wood or cause extensive decay in living trees.
2. White rots are the most common decay fungi. White rots break down lignin as well as, to various extents, both cellulose and hemicellulose in cell walls, leaving spongy, flexible wood that is often white in appearance. As the wood flexes and experiences movement due to loading, response growth usually develops, which may compensate for the strength loss in that location and provide visual clues to the presence of the decay.
3. Brown rot decay fungi break down cellulose and hemicellulose but generally leave the lignin intact. Brown rots are stiff and brittle and are found primarily on conifers.
4. Compartmentalization is a process in which trees react to wounding to limit the spread of damage, dysfunction, and decay within the wood. The basic components of compartmentalization are new cell formation in new wood, chemical changes, and the existing growth rings and boundaries created by rays and other living cells.
5. CODIT is a simplified model of the compartmentalization process. The first three CODIT walls are composed of preexisting wood tissue that changes after injury to serve a defense function (the reaction zone). Wall 4, the barrier zone, consists of new cells that are anatomically and chemically different from cells formed prior to wounding. Wall 4 is the strongest and most important of the defenses.
6. A tree may appear to be healthy, solid, and structurally sound, but there may be decayed areas of wood inside even if fruiting bodies are not present.
7. Internal decay is very common in urban trees, and it is usually only important when extensive amounts of the cross-sectional area is decayed, or when associated with other defects such as codominant stems.

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Tree Biology and Mechanics

Module 5, Part 3: Mechanics

Learning Objectives

- Explain the concept of load and list the primary sources of loads that trees may experience.
- Describe the principle of bending moment and give an example of how it applies to trees.
- Explain how tension, compression, shear, and torsion affect trees.
- Discuss how trees respond to wind and how they dissipate or transfer wind forces.
- Explain why evaluating the load-bearing capacity of stems can be important in risk assessment and discuss the limitations of the formula commonly used.
- Discuss the considerations for assessing loads on trees.

Key Terms

bending moment	dynamic	load	shear
biomechanics	force	load-bearing capacity	static load
center of gravity	frequency	mass damping	stress
center of pressure	friction	mechanics	stress raisers
compression	lever	moment	taper
damping	lever arm	neutral plane	tension
drag	live crown ratio	reconfigure	torsion

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Introduction

Mechanics is the study of how objects respond when forces act on them. **Biomechanics** is the application of mechanical principles to living organisms. In tree risk assessment, assessors use concepts of mechanics to assess likelihood of failure. Specifically, assessors apply mechanics to understand the loads a tree experiences and its **load-bearing capacity**. Failure occurs when the loads exceed the load-bearing capacity. In this section, the factors that influence loads and load-bearing capacity are examined. This section also addresses how to apply mechanical concepts to assessing the likelihood of failure, different types of loads, how loads and load-bearing capacity relate to mechanical stress and wood strength, and how trees respond to loading.

Loads on Trees

Load is a generic term that includes both **forces** and **moments**—actions that cause rotation around an axis—that act on a structure. The two natural forces that act on trees are gravity and wind. Gravity acts as a constant pull on the mass of the tree, generating a mostly **static load** from self-weight and the weight of water (condensation, rain, snow, or ice) on leaves and branches. Gravity also exerts a static load on the mass of anything else in the tree such as vines, epiphytes, or climbing arborists and their gear. A static load is one that does not change quickly over time.

The force that wind exerts on a tree is called **drag**. The amount of drag depends primarily on wind speed, crown area, air density, and drag coefficient. Drag increases in relation to the square of wind speed, which suggests that small changes in wind speed can lead to large changes in drag. Crown area is based on the size and shape of the tree crown (i.e., leaves and branches) which can change based on wind speed as the crown **reconfigures** and becomes more aerodynamic. Reconfiguration occurs as the wind speed increases; leaves change shape and small branches bend away from the wind. Assessing airflow around a tree crown is not always intuitive—a dense crown may not obstruct airflow as much as a porous one. There is not enough research on airflow

Definitions of Some Key Terms

Several key terms are required for understanding tree biomechanics. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

bending moment—the load that results from a force acting on a lever, causing a structure or member of the structure to bend; it is calculated by multiplying the force that acts perpendicular to the lever by the length of the lever.

compression—in mechanics, the action of forces to squeeze, crush, or push together any material(s).

force—any action or influence causing an object to accelerate/decelerate.

load—a general term used to indicate a force, bending moment, torque, or pressure applied to a substance or material.

load-bearing capacity—the capacity of a structural member or material to carry a load before failure occurs.

stress—in mechanics, a force per unit area.

tension—in mechanics, the action of forces to stretch or pull apart any material.

Asplundh Tree Expert Company

Figure 5.30 Freezing rain can accumulate on twigs and branches, creating a very heavy load that often causes failure.

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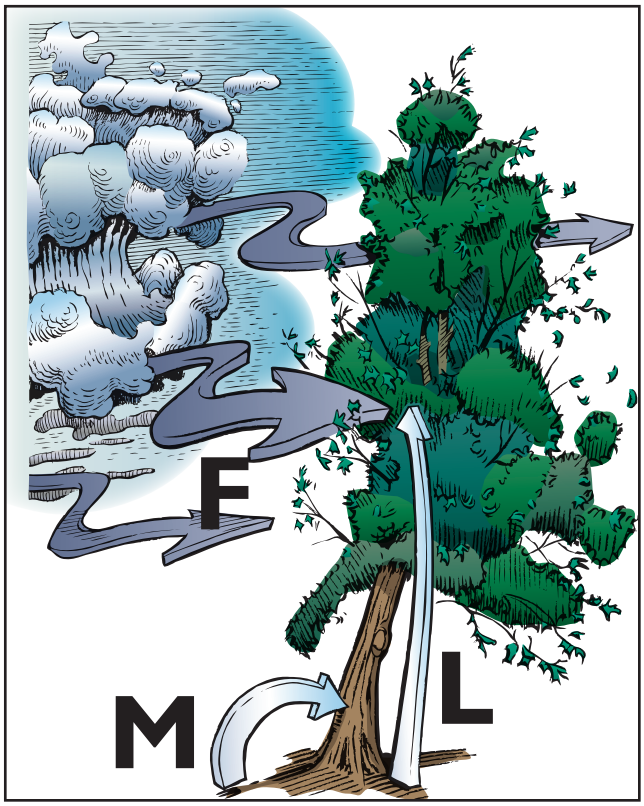
to make consistent and reliable recommendations. Drag also changes with air density, but air density does not meaningfully change within the range of elevations in which trees grow.

Unlike the static force exerted by gravity, drag changes relatively quickly over time; on a windy day, the wind speed (and, in turn, the drag) can change within a matter of seconds. Forces that change over short periods of time are described as **dynamic**, and they may be more likely to cause failure under certain conditions. Other examples of dynamic loads that can cause tree failure include those imparted during earthquakes, floods, and climbing or rigging.

Forces often act over a **lever**, such as when drag acts on the tree crown or when gravity acts on a horizontal branch. The lever is the distance between the location where the force acts (in the crown or along the branch) and the location where the tree or branch is held in place (in the ground or at the branch union). The lever can also be a distance from the center of pressure in the crown to a large cavity in the trunk. When a force acts on a lever, it creates a moment. The moment is calculated by multiplying the force by the length of the lever.



Bryan Kotwica

Figure 5.31 Wind affects the entire tree crown but is often calculated as the force (F, total drag) on the crown acting at a single point, which is the center of pressure. The bending moment (M) on the tree is calculated by multiplying the force (F) by the lever (L), which is the distance from the ground to the center of pressure.

Moments are described by the resulting action. A **bending moment** is a load that results in a bending action, such as when a branch bends under the added weight of snow or ice. A twisting moment is the load that results in a twisting action, such as when an arborist applies a twisting force to rotate the locking mechanism on the gate of a carabiner.

Given the complex nature of wind and the difficulty of measuring the surface area of the leaves, twigs, and branches in the crown, bending moments caused by wind are estimated by assuming that the drag acts at the height of the **center of pressure** of a tree crown. If the crown is approximately circular or elliptical in shape, the center of pressure is located approximately at the center of the crown. For more cone-shaped crowns, the center of pressure is located approximately one-third of the distance from the base to the tip of the cone. When gravity acts on a horizontal branch, it is customary to assume that the weight of the branch is applied at the branch's **center of gravity**. The center of gravity is a point on the branch where it would balance and remain horizontal (i.e., parallel to the ground) if it were supported at a single point.

Load-Bearing Capacity of Trees

The load-bearing capacity of branches and trunks depends primarily on their size and inherent material strength. Size is usually considered as the branch or trunk diameter, assuming that it is roughly circular in cross section. If the cross-sectional shape is more oval (elliptical) than circular, then the load-bearing capacity will also depend on the direction of an applied load. As the diameter increases, so does the load-bearing capacity. This is expected from the formula to calculate stress: as the area of wood increases, the stress decreases.

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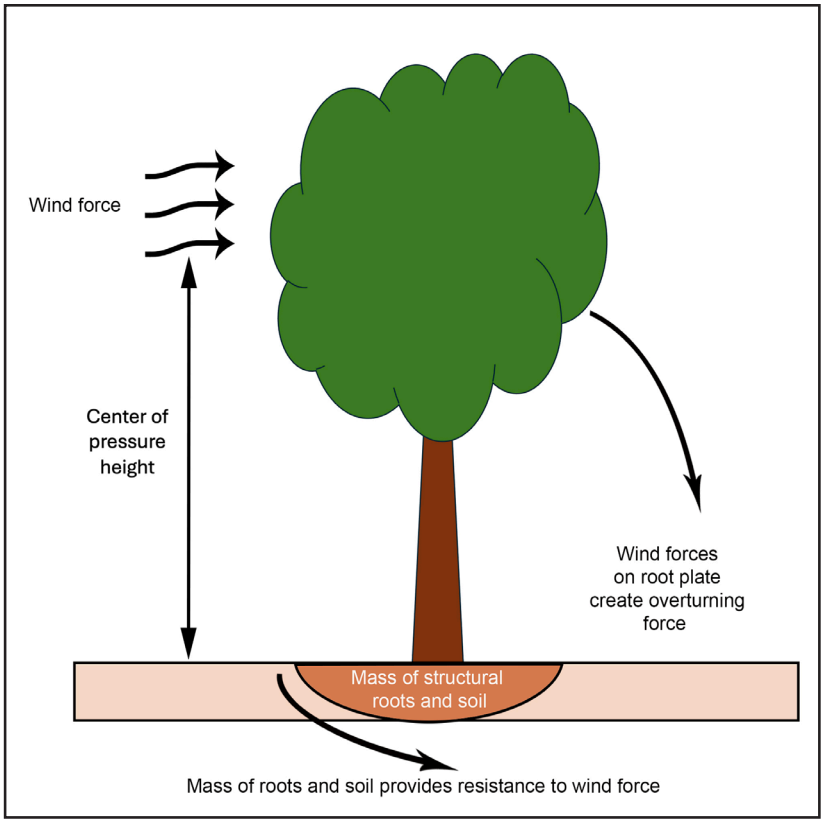
Material strength also influences the load-bearing capacity because stronger materials can bear greater loads. An example is the strength of wood with and without decay; it is much easier to break a decayed branch than one that is not decayed. In addition to the difference in strength of wood with and without decay, wood strength is also different for different species, different trees of the same species, even different parts of the same tree.

The load-bearing capacity of the roots depends on root diameter and strength of the wood in the roots. But this only applies when roots break in the same way that a branch or trunk breaks—by the wood fracturing. Trees can also uproot when roots pull out of the soil or when the soil itself fails; in both instances, soil properties affect the load-bearing capacity. **Friction**, the resistance to movement when two surfaces are in contact, is the important force in both instances—friction between roots and the soil or friction between soil particles themselves.



Julian A. Dunster

Figure 5.32 The mass of a tree root plate must be sufficient to resist the bending moment applied by the wind, which is drag on the crown multiplied by the center of pressure height.

The bending moment that the wind exerts on a tree is resisted by the combined mass of the roots and soil. If there is not enough friction between the roots and soil to resist the bending moment, the roots will pull out of the soil and the tree will uproot. Friction between roots and soil, as well as between soil particles themselves, depends on soil texture and moisture content. Friction is less in coarse, sandy soils and greater in fine, clayey soils. Friction is also less in saturated soils. Uprooting is more common when soils are saturated because less friction means that a smaller root-soil mass will be available to resist the bending moment applied by the wind.

Load-bearing capacity of the root-soil mass will be reduced when structural roots are cut or damaged. As a greater proportion of the structural roots is cut, the likelihood of uprooting or windthrow will increase.

Stress

Loads and load-bearing capacity are linked by a mechanical concept called **stress**. External loads—forces and moments applied to a tree—lead to internal stresses in the wood. Stress is the distribution of an external load over the cross-sectional area of wood at a particular location in the tree. It is computed as a ratio: Stress = Load / Area. Increasing the load does not necessarily increase the likelihood of failure because a larger cross section in a branch, trunk, or root provides a greater area over which the large load is distributed.

Wood in a tree experiences four types of stress (Figure 5.33):

Compression is squeezing a material.

Tension is stretching or pulling a material, the opposite of compression.

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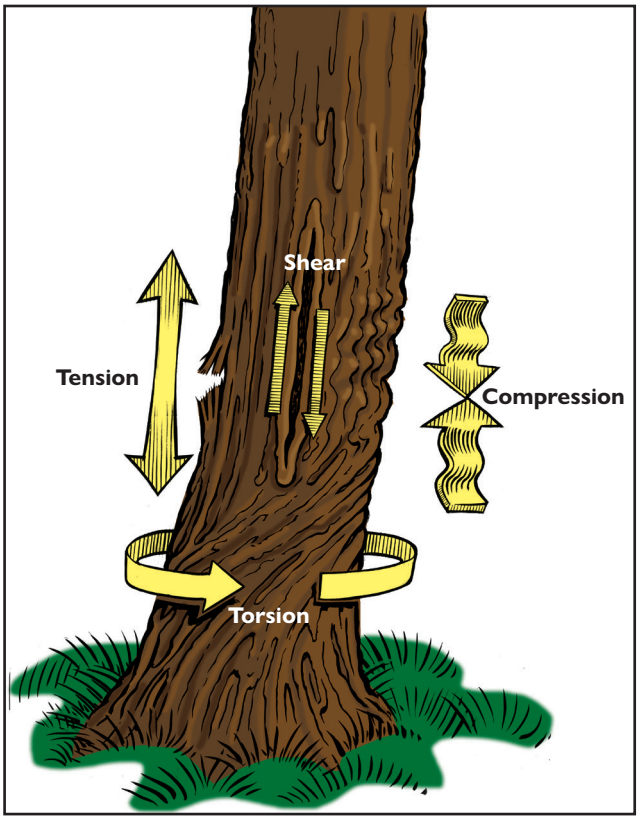
Shear occurs when components of a material attempt to slide along adjacent components; it is greatest at the **neutral plane** of bending where compressive and tensile stresses meet.

Torsion is a type of shear stress caused by a twisting moment. This can occur if most of the branches in the crown are on one side because drag will act mostly on that side of the tree. It could also occur if there were many more secondary branches on one side of a primary branch that was loaded by snow or ice.

Stresses can occur alone or in combination. When gravity acting on a branch pulls or bends it downward, the bending moment creates tension in the top of the branch (fibers are stretched) and compression in the bottom of the branch (fibers are pushed together). In the middle of the branch, the neutral plane experiences shear stress, where the fibers in tension and those in compression meet and try to slide in opposite directions. Bending, therefore, involves three stresses: compression, tension, and shear. If the branch also experiences a twisting moment, it will be subjected to all four types of stress.



Bryan Kotwica

Figure 5.33 The four basic stresses within a tree are compression, tension, shear, and torsion.

The greatest bending and torsional stresses occur at the perimeter of the stem's cross section. This is why a stem can be hollow in the center but still retain much of its load-bearing capacity. On the other hand, decay, or cavities at the perimeter of the stem can reduce the load-bearing capacity even if the same amount of decay would not cause concern if it were in the center of the stem.

Load-bearing capacity depends on both cross-sectional area and inherent wood strength. Unlike some materials, wood strength varies depending on the type of stress it experiences. Wood is about twice as strong in tension as wood under compression, which is why a bent stem will fail first in compression. Wood also tends to be stronger in bending than shear. This variability adds a layer of complexity to assessing likelihood of failure. A helpful example of this is a shear crack in the middle of a branch that remains attached to the tree. In that case, the shear stress exceeded the shear strength of the wood and the branch failed in shear, as shown by the crack. But the branch did not fail in bending—the bending stress did not exceed the bending strength of the wood—so the branch remains in place.

Applying Mechanical Principles to Likelihood of Failure

It is difficult to predict the loads a tree will experience and its load-bearing capacity. Usually, when assessing likelihood of failure, tree risk assessors inspect for and assess conditions that may lead to increased loads or decreased load-bearing capacity. In addition, tree risk assessors should consider the tree's ability to compensate for changes (response growth). Understanding mechanical principles related to load and load-bearing capacity can therefore help in assessment of the likelihood of failure.

An example of applying mechanical principles to understand loading involves assessing changes in land use. Trees previously sheltered by neighboring

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trees or buildings can grow with more slender trunks because they are exposed to smaller wind loads. But if development removes the shelter and exposes slender trees to greater drag, the likelihood of failure will increase because the previously sheltered trees do not have the same load-bearing capacity. Another example of applying mechanical principles to understand loading is assessing the funneling effect of nearby buildings, trees, or topography on wind speed and the drag trees experience. When wind is squeezed into a smaller space, such as when it moves between two tall buildings, it accelerates. The resulting increase in wind speed creates greater drag than a downwind tree will experience.

Examples of applying mechanical principles to understand load-bearing capacity include assessing the effect of defects and response growth. Defects that reduce a tree's load-bearing capacity include decay and cavities, weakly attached branches and codominant stems, and cracks. Response growth can sometimes compensate for the loss in load-bearing capacity because of the new wood that is formed in the vicinity of a defect.

Decayed parts of a tree and the response growth that may form in the same part provide a good example of how to apply mechanical principles to assessing load-bearing capacity. Decay and response growth also illustrate the relationship between load-bearing capacity, stress, and wood strength. When decay is not present in a cross section of a tree, the stress it experiences is the ratio of the loads it bears to the area of the cross section. The likelihood of failure depends on whether the stress in the cross section exceeds the wood strength. When incipient or intermediate decay is present, the load-bearing capacity will be reduced because the strength of decayed wood is less than the strength of wood without decay. It is important to understand that stress would be the same because the area of wood in the cross section remains the same. If advanced decay or a cavity is present, the load-bearing capacity is reduced because there is less wood in the cross section. Because stress is the ratio of loads to the cross-sectional area of wood, a reduction in area means an increase in stress.

Response growth can compensate for the loss in load-bearing capacity due to decay or a cavity. Response growth may also be inherently stronger than normal wood in the tree and therefore able to endure greater stress if a cavity is present. Response growth may also form at areas of locally increased stress. Common occurrences of this are where a stem grows in a sharp angled bend or where a canker is present. These situations are referred to as **stress raisers**, which may act as a point where failure begins. It is important to recognize stress raisers and assess how they may be loaded.

Loss in Load-Bearing Capacity Due to Hollow/Decay

Arborists have considered the effect of decay on load-bearing capacity for many years. An important question is, "What amount of solid wood is necessary to maintain adequate load-bearing capacity?" Another way to ask this question is, "What extent of decay increases the likelihood of failure too much?" The extent of decay refers to both the amount of

Richard Hauer

Figure 5.34 The loss in load-bearing capacity depends on the amount of decay and its location in the cross section. Off-center decay reduces load-bearing capacity more than concentric decay. If the solid-wood thickness is being determined by drilling, the points at which the tree is drilled can greatly affect the measurements.

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Frank Rinn

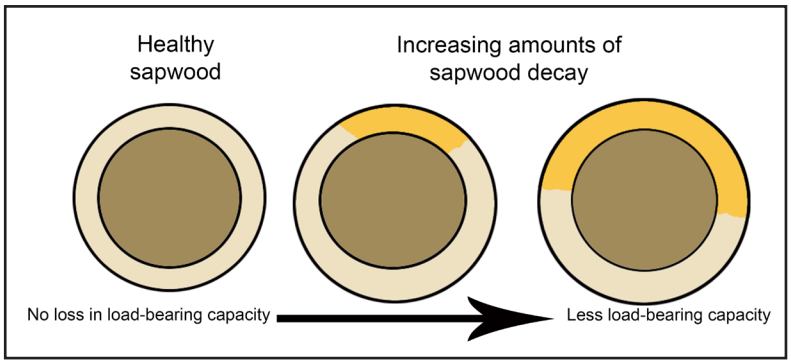
Figure 5.35 Formulas to determine the loss in load-bearing capacity due to decay assume that the cross section and area of decay are circular. The loss in load-bearing capacity depends on the amount of decay and its location in the cross section. Off-center decay reduces load-bearing capacity more than concentric decay.

decay and its location in the cross section; both factors affect the loss in load-bearing capacity.

In one type of an advanced (Level 3) risk assessment, assessors perform tests to estimate the location and extent of decay and the remaining amount of solid wood. The amount of solid wood remaining is often expressed as the thickness of solid wood around the cavity or area of advanced decay. If the decayed area is located in the center of the cross section the loss in load-bearing capacity can be estimated from a ratio of the diameter of the hollow/decayed area to the diameter of the cross section. The output of this calculation shows that the load-bearing capacity significantly decreases when the diameter of the hollow/decayed area is greater than 70 percent of the cross-sectional diameter (solid wood remaining is 30 percent of the diameter). As a guideline, the average solid wood thickness around a cavity/decayed area should be more than 15 percent to avoid a significant reduction in load bearing capacity. As solid wood thickness decreases below 15 percent, likelihood of failure increases.

Assessors should not assign a likelihood of failure rating based only on the 15 percent ratio; loading and other limitations should be considered:

- The ratio assumes that the tree cross section and the area of decay are circular, which may not be true.
- When cavity/decay is off-center, the loss in load-bearing capacity cannot be estimated based on the 15 percent guideline.
- Response growth can be stronger than normal wood.
- Wood strength differs by species and among different parts of the same tree.
- Wood strength differs with the direction of loading: strength is greater in tension than in compression.
- Trees with large diameters (> 30 in [75 cm]) can tolerate a greater amount of decay.
- The presence of other defects can influence the likelihood of failure when decay is present. If a decayed tree is leaning or there is decay near a crack or weak branch attachment, the other factors will increase the likelihood of failure, even if the loss in load-bearing capacity due to decay is not very large.



Nelda Matheny

Figure 5.36 If the amount is the same, sapwood decay reduces load-bearing capacity more than heartwood decay because the outermost wood is damaged.

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- A tree protected from the wind or a shorter tree does not need as much load-bearing capacity as a tree fully exposed to the wind or a taller tree.
- The guideline does not directly apply to root decay.

For the same area of decay, there is a greater loss in load-bearing capacity when the decayed wood is in the sapwood rather than the heartwood. This is because the outer wood in a stem contributes much more to load-bearing capacity than the inner wood. As the proportion of sapwood decay around the circumference of the stem increases, the loss in load-bearing capacity at that location increases significantly.

Brian Kane

Figure 5.37 Slenderness is the ratio of tree height to trunk diameter at breast height; slender trees may have a greater likelihood of failure if nearby trees that had sheltered the slender tree are removed.

Live Crown Ratio

Live crown ratio is the ratio of the height of the foliated parts of the crown to the total height of the tree, expressed as a percentage. The location of live branches and foliage in the tree influences how the tree is loaded by the wind and precipitation. If live branches and foliage are limited to the highest parts of the crown, drag acts mostly near the top of the tree; consequently, it acts over a long **lever arm**, which causes a larger bending moment at the root collar for the same amount of drag. Greater live crown ratio, where the live crown occupies a greater proportion of tree height, means the lever arm will be shorter because the center of pressure is closer to the root collar. If the area of live branches and foliage is the same as for the tree with its live branches and foliage near the top of the tree, the bending moment will be smaller because the lever arm is shorter. Sometimes, it is not as simple as these examples suggest, which may introduce uncertainty in assessing loads from live crown ratio.

Slenderness

The ratio of tree height to trunk diameter at breast height (DBH) is a measure of the tree's slenderness. Slenderness can also be measured for branches using their length and basal diameter. Slender trunks or branches have low **taper**, their diameter does not change very much along their length. Slenderness and taper can affect the likelihood of failure because they affect where stress will be greatest. Slender trunks and branches do not necessarily have a greater likelihood of failure because slender growth often occurs as trees compete for sunlight. If nearby trees or structures protect a tree from wind loads, it does not need a stout, well-tapered trunk and branches because it experiences small loads. But if site changes suddenly expose a tree with a slender trunk and branches to larger loads, the likelihood of failure will increase.

Tree Response to Loads

Trees respond to loads by bending or twisting. And just as loads can be static or dynamic, a tree's response can also be static or dynamic. Under the

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CASE STUDY

The Need for an Advanced Assessment

Assignment: The park manager (tree risk manager) assigned their in-house tree risk assessor (TRAQ) to assess the risk of a black peppermint eucalyptus (*Eucalyptus amygdalina*) adjacent to a picnic shelter.

Time Frame: Two years.

Targets and Site: Targets include the picnic shelter (*constant* occupancy), people, and parked cars. The presence of people and parked cars was considered *frequent* occupancy during most of the year due to the favorable climate and popularity of the site.

The shelter has been present for at least 20 years. The soil is compacted and dry, and the tree has full wind exposure.

Tree Condition: The tree lost one codominant stem in a storm four years ago. Decay is visible inside the stump of the lost stem and within the remaining stem. Some obvious response growth has begun to close the wound on the remaining stem, strengthening the stem at the base. Some root damage is visible, including several small girdling roots. The crown is full and dense, but growth has been declining during the last few years.

Analysis: This formerly vigorous tree is showing some signs of decline, probably due to poor root and soil conditions.

Response growth is extensive and appears to have already partially compensated for the loss in load-bearing capacity due to decay. Loading remains a significant concern due to the lean of the remaining

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stem, the unbalanced crown, and the density of the crown. Likelihood of failure cannot be determined without further testing.

The likelihood of impacting the shelter is *high*, although based on *frequent* occupancy, the likelihood of impacting a person is *medium*. The consequences of impacting the shelter are rated as *minor*, but they would be *severe* for people and *significant* for cars. The risk to people in the area could range from *low* to *high*, depending on the likelihood of failure.

Recommendation: Further testing is needed to determine the extent of decay and response growth and the overall stability of the tree. If the likelihood of failure is *improbable* or *possible*, measures should be taken to improve root health and to reduce crown weight toward the shelter. Lean and condition should be reassessed annually. If the likelihood of failure is determined to be *probable* or *imminent*, the risk will exceed the tree risk manager's stated threshold, and the tree should be removed.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photos by Doug Sharp

weight of snow or ice, a branch will bend or twist slowly, perhaps imperceptibly, as the load increases over minutes or hours. If loaded by a gust of wind, tree motion is easily visible. When drag is small, only the smaller parts of the tree (leaves and twigs) bend or twist. As drag increases, the size of tree parts that bend or twist also increases. The amount of bending and twisting depends on the amount of drag.

For both static and dynamic loads, the amount of bending and twisting also depends on the stiffness of the branches, trunk, and roots. As diameter increases, the amount of bending or twisting decreases. Large trees with lots of leaves experience very large bending moments on windy days, but because trunk diameter is also large, the trunk itself bends very little. Most of the bending occurs in tree parts that are smaller in diameter.

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Because dynamic loads change quickly, even though a tree responds by bending or twisting, when the load decreases, the bent or twisted part will eventually return to its original position. However, this does not occur slowly. Instead, the return of a tree part to its original position causes the part to sway back and forth before eventually coming to rest. The swaying motion associated with dynamic loads has two important characteristics for assessors to understand.

The first characteristic is **frequency**, which describes (1) how quickly a tree or tree part sways—the sway frequency; and (2) how quickly successive gusts of wind exert drag on the tree—the gust frequency. If the sway frequency and the gust frequency are similar, then the repeated gusts of wind cause the tree to experience larger sways with each consecutive gust. Larger sways are generally associated with greater likelihood of failure.

The second characteristic is **damping**, the process through which the swaying motion of a tree or tree part(s) dissipates wind energy. If a tree is heavily damped, the duration of motion following a gust of wind will be short, and the tree may be moving very little by the time another wind gust acts on the tree. If the tree stops (or nearly stops) moving more quickly, the likelihood of tree failure will decrease, assuming other factors remain unchanged. But if the tree is only lightly damped, its motion following a wind gust will continue for longer, and a subsequent wind gust may force the tree into greater motion. If other factors remain constant, the likelihood of failure of a lightly damped tree is generally greater than a heavily damped one.

Damping is affected by a variety of factors. Among the most important are the amount of leaves in the crown and the possibility for branches in the crown to collide with one another or with an adjacent crown. The presence of leaves increases damping because leaves experience drag as the tree sways. When leaves are absent, swaying can continue for longer. Wind energy is also dissipated when branches collide with nearby branches on the same tree or a neighboring tree. Such collisions can also reduce the

Mechanical Responses to Wind

Trees respond to wind by:

- Reconfiguring leaves, twigs, and branches (immediately in the present wind and more permanently when exposed to constant or frequent wind)
- Only slowly increasing height (trees in areas of strong wind tend to be shorter than the same species with less wind exposure)
- Increasing diameter
- Altering root growth (long, ropelike roots on the windward side; stocky, prop-like roots on the leeward side)
- Forming thicker branch unions
- Changing mechanical properties of the wood (forming reaction wood)

Frank W. Telewski

Figure 5.38 Over time, trees conform their shape to be more aerodynamic when there is a strong prevailing wind. This "flag" tree exhibits reduced height, one-sided branching, and streamlining of smaller branches and twigs.

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likelihood of tree failure. **Mass damping** describes the movement of branches in a tree at different frequencies which dissipates wind energy at the branch rather than transferring it to the trunk and roots. The less wind energy that is transferred to the trunk and roots, the less likely they are to fail. Sway frequency depends on diameter and length; if there are many branches of different sizes in the crown, their motion will not be uniform, which results in the trunk and roots experiencing smaller loads.

Trees also respond to loads by adding wood where it is needed to increase load-bearing capacity. An example of this is a tree growing in a location where the wind nearly always comes from the same direction. In such cases, the cross section of the trunk will likely be more oval than circular in shape, which gives the tree greater load-bearing capacity in the wind direction. It is important for assessors to consider the effect of site changes that may expose such a tree to loads from a new direction because the tree had not developed load-bearing capacity in that direction of loading.

Assessing Loads on Trees

Assessing the loads a tree experiences is an important part of assessing the likelihood of failure because failure will occur when the loads exceed the tree's load-bearing capacity. Trees experience a variety of loads, both static and dynamic, including self-weight; the weight of rain, snow, or ice; the weight of other objects in the crown like a climbing arborist or vines; forces associated with rigging; and drag.

The amount of loading can vary. The same tree will experience greater drag if the wind speed is 60 mph (97 km/h) than if wind speed is 10 mph (16 km/h).

E. Thomas Smiley

Figure 5.39 Sharp bends, such as the one near the branch union of this branch, can be points where mechanical stresses are magnified. Stress raisers, such as torsional cracks and ribs, cavities, and old pruning cuts, can also be seen in this tree.

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CASE STUDY

Assessing the Extent of Internal Decay

Assignment: Advanced risk assessment to determine the extent of decay in a trunk

Time Frame: Four years

Target and Site: Tree with codominant stems growing near an historic home in a residential neighborhood; the site is generally windy because it is on an exposed hill.

Conditions: A basic risk assessment of the white ash (*Fraxinus americana*) indicated the possibility of decay in the trunk and one or both of the codominant stems. In the crown, advanced decay was obvious at the site of an old branch failure and, higher up, an older pruning cut.

When struck with a mallet, the lower trunk sounded solid, and there was a closed seam starting at the base of the trunk. The homeowner did not want to remove the tree unless the risk was *high* or *extreme*.

Analysis: On the ground and from an aerial lift, the tree risk assessor used a battery-powered portable drill to determine that there was a central column of decay surrounded by a uniform thickness of sound wood in the trunk and both of the codominant stems. Just above the root collar, the trunk diameter is 30 in (76 cm) and the average thickness of sound wood is 9 in (23 cm). Just above the union, the diameter of the codominant stem that leans away from the house is 20 in (51 cm), and the average thickness of sound wood is 3 in (8 cm); the diameter of the codominant stem that leans towards the house is 15 in (38 cm) and the average thickness of sound wood is 1 in (2.5 cm). The tree is otherwise healthy and has a full crown.

Risk Categorization: Even though the tree is exposed to the wind and the crown is full, the likelihood of trunk failure is *improbable* because the thickness of sound wood is 30 percent of the trunk diameter. The likelihood of failure of the codominant stem that leans away from the house is *possible* because of the windy site, full crown, and the thickness of sound wood is 15 percent of the stem's diameter. The likelihood of failure of the codominant stem that leans towards the house is *probable* because of the windy site, full crown, and the thickness of sound wood is only 7 percent of the stem's diameter. The likelihood of impact is *high* because the target is within the dripline, has *constant* occupancy, and is unprotected. Consequences are *significant* because of the size and fall distance of the codominant stem. Combining a *probable* likelihood of failure with a *high* likelihood of impact means that the likelihood of failure and impact is *likely* in the four-year time frame. The *significant* consequences and the *likely* likelihood of failure and impact leads to *high* risk.

Recommendation: Remove the codominant stem leaning towards the house; retain the tree and reassess in two years.

Residual Risk: If the codominant stem leaning toward the house is removed, the residual risk would be *low*. The codominant stem leaning away from the house has *low* risk because the likelihood of failure

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is *possible*, the likelihood of impact on the boxwood hedge is *high*, and the consequences of damaging the boxwood hedge are *negligible*.

The homeowner had the stem removed and scheduled a reassessment for the next year.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photo by Brian Kane

Branches in particular experience a wide range of loads. On a deciduous tree, branches experience less drag when leaves are absent. Similarly, a leafless, dead branch experiences less drag. As the wood in a dead branch decays, it loses weight and the branch will experience less loading.

It is also important to assess a load in relation to a defect that has reduced the load-bearing capacity. The likelihood of failure of a fully leaved, weakly attached branch with included bark that experiences gale force wind will be greater than a short dead branch that experiences a rain shower. And a load may not act on the entire tree—a climbing arborist ascending into the tree primarily loads the anchor point—so it is important to understand how a particular load will act on a particular tree part.

The presence of stress raisers—cankers, cracks, sharp bends, or other factors that can magnify the stress—is another reason to consider where a load acts in the tree. Asymmetrical crowns and overextended branches may also experience greater loads and it is important for assessors to consider that they can have a greater likelihood of failure under load.

In one type of an advanced (Level 3) risk assessment, sophisticated measurements and models are used to predict the loads a tree will experience. Methods such as this require the use of sophisticated measuring instruments and knowledge of their implementation and limitations. The models are limited by the uncertainty that clouds some of the measurements; combining uncertain measurements increases the amount of uncertainty.

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Summary

Understanding basic mechanical concepts enables an assessor to better assess the factors that influence loads and load-bearing capacity, such as defects, response growth, species, crown form, exposure, site changes, and weather that ultimately determine the likelihood of failure. Assessors should consider that all trees, even if they have strong wood and no defects, will fail when loads are large enough. This can occur during extreme weather such as hurricanes, tornadoes, and ice storms.

Key Concepts

1. Load is a general term to include forces and moments. Trees fail when the loads they experience exceed their load-bearing capacity, so it is important to consider loading as part of a tree risk assessment.
2. The two natural forces that act on trees are gravity and wind. When they act over a lever, the force is multiplied by the length of the lever, causing a bending or twisting moment.
3. Strength is defined as the ability to withstand stress without failure. In general, wood is about twice as strong in tension as in compression.
4. The ratio of a load to the cross-sectional area that experiences the load is called stress. There are four types of stress: Compression is squeezing a material; tension is stretching a material—the opposite of compression. Shear stress results when parts of a material attempt to slide relative to one another. Torsion creates a special type of shear stress caused by a twisting force. Stresses can occur alone or in combination.
5. Precise computations of load and load-bearing capacity are difficult to make, so assessors typically focus on factors that increase or decrease loads and load-bearing capacity, such as site changes exposing a previously protected tree to greater wind load. Defects increase stress and reduce load-bearing capacity. If a tree experiences smaller loads, it does not need as much load-bearing capacity. Site changes can change the loads a tree experiences, which may increase the likelihood of failure.

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Tree Inspection and Assessment

Module 6

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Tree Inspection and Assessment

Module 6

Learning Objectives

- List and describe common defects and conditions associated with tree failures.
- Describe the structural implications of defects and response growth and explain how they can interact to either increase or decrease the likelihood of failure.

Key Terms

adventitious branch
bow
bulge
canker
cavity
codominant
corrected lean
crack
decay
defect
definite indicator
epicormic shoot
freeze–thaw crack
frost crack
girdling root
included bark
lean
live crown ratio
oozing
overextended branch
potential indicator
rib
ridge
sapwood decay
seam
shear plane crack
sudden branch drop (SBD)
sweep
taper
transverse crack
tree architecture
visual assessment

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Introduction

A key part of tree risk assessment is categorizing the likelihood of failure. In a basic tree risk assessment, the tree risk assessor looks around the tree and systematically conducts a **visual assessment** of the crown, branches, trunk, root collar, visible roots, and site conditions. The assessor should identify the load factors, defects, and conditions that would increase or decrease the likelihood of failure. Two important elements to consider when determining likelihood of failure: 1) the loads that the tree may experience within the defined time frame; and 2) structural defects and conditions that may reduce or increase a tree's load-bearing capacity. Trees fail when the load(s) they experience exceed their load-bearing capacity.

What Are Defects?

In tree risk assessment, **defects** include injuries, growth patterns, decay, or other conditions that reduce the tree's structural strength. There are many types of defects, each with implications for tree strength or stability. Even conditions such as growth patterns, tree architecture, and heavy fruit crops can sometimes affect the likelihood of failure. Individual defects or conditions may or may not indicate a serious structural problem. Some defects may be important, while others may not be serious threats to the structural integrity of the tree. At times, a single defect alone is not an issue, but in combination with other factors such as recent or planned changes in site conditions, may become important in the risk assessment process. If more than one defect or condition is present, the likelihood of failure may be increased.

The cross-sectional shape of the trunk may offer some clues about internal structural weaknesses. A vertical trunk will be approximately cylindrical. If the cross section is not cylindrical, then there may be structural issues that need to be investigated such as heartwood decay or cracks.

Poorly attached bark, cracked bark, areas of abnormal bark color or pattern, and resin flow or **oozing** sap through the bark are all potential indicators of a defect. If they have been present for many years, they may indicate mechanical damage and/or decay behind the symptomatic area.

Flat areas at the root flare may indicate missing (cut or decayed) roots, **girdling roots**, or root growth obstructions such as a strap, rope, rocks or underground infrastructure. Other root-related problems such as buried buttress roots can affect root decay or response growth, which, in turn, affect tree stability. If roots are severed, decayed, broken, undermined, or restricted, they may reduce anchorage. Structural

Definitions of Some Key Terms

Several key terms are required for understanding tree defects and how to interpret them. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

canker— localized, diseased, usually necrotic area on stems, roots, and branches.

codominant stem—forked branches of nearly the same diameter, arising from a common union and lacking a branch collar; may have included bark.

crack—separation of wood fibers.

defect—an imperfection, weakness, or lack of something necessary. In trees, defects are injuries, growth patterns, decay, or other conditions that that may predispose a tree to failure.

included bark—bark that becomes embedded in the union between branch and trunk or between codominant stems.

sapwood decay—decay located in the sapwood. Bark and/or cambium may be damaged or dead.

seam—lines formed where two edges of bark meet at a crack or wound.

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E. Thomas Smiley

Figure 6.1 Visual assessment includes looking for and determining the significance of defects and structural conditions. Consider defects, response growth, loads, and conditions that may increase or decrease the likelihood of failure. Individual defects or conditions may not by themselves indicate a serious structural problem but, in combination with other conditions, may contribute to failure.

problems with roots are not the only cause of failures belowground. Some soils allow excessive movement of roots, especially when the soil is saturated.

Root problems can be very difficult to detect, and root failures can be difficult to predict. Soil and site conditions around the tree can often provide information about changes that have occurred, which may have damaged the root system or affected soil strength.

Defects and the Likelihood of Failure

In this module, many types of defects and conditions that could affect a tree's likelihood of failure are discussed. In some cases, guidance for categorizing the likelihood of failure is given. A three-year time frame is used in these examples for consistency and comparison, but tree risk assessors and managers should select a time frame that is appropriate for the situation.

Visual assessment of the tree crown, stem, and branches can reveal a great deal about the structural condition of the tree. For example, trees that have experienced branch failure in the past may be more likely to experience branch failure in the future. The tree risk assessor should look for patterns of weak branch attachments, decay, decline, poor weight distribution, and other conditions associated with previous failures. Failure of additional, similarly constructed branches may be considered *possible* to *probable* within a three-year time frame.

Response growth should also be considered during risk assessments. Response growth can strengthen weak areas—regaining load-bearing capacity lost because of the presence of a defect—thereby reducing the likelihood of failure.

When more than one defect or condition is present in a tree, their combined effect on the likelihood of failure should be considered. For example, a trunk lean of 10° may not be of great concern on many trees, but if a large, decayed root is also present, then the likelihood of failure can increase.

A visual assessment includes identifying and determining the significance of each of the structural conditions, individually and in combination, that increase or decrease the likelihood of failure. However, not all defects will be apparent during a limited visual or a basic tree risk assessment. Heartwood decay, root loss, lack of soil strength, and other defects may not have visible symptoms.

There may be variation among tree species, decay fungi, defects, and site conditions. The estimation of loads, defects, response growth, failure, and other conditions is not an exact science. Because of this, tree risk assessors and managers must recognize that there is uncertainty in any tree risk assessment. This module describes common structural defects and

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conditions, along with response growth patterns that affect likelihood of failure, and provides guidance for categorizing the likelihood of failure.

Guidance is provided to assist tree risk assessors with categorizing the likelihood of failure for some of the defects and conditions described. Tree risk assessors should consider loads, load-bearing capacity, response growth, defects, and additional conditions when assessing trees.

Dead or Dying Parts

When a target is present, dead trees are an obvious concern, as are dead or dying branches and roots. However, some species can remain standing and hold dead branches for many years, so familiarity with tree species and local climate is important.

Signs and symptoms of dead trunks or branches include a lack of leaf growth; dead, loose, or missing bark; missing buds; and broken or blunt branch tips. The larger the size of the dead part and the higher it is above the target, the greater the concern. Dead or loose bark often can be detected by sounding the trunk with a mallet.

Dead branches vary in their likelihood of failure from *possible* to *imminent* in a three-year time frame, depending upon the species, branch weight, the type and extent of decay, infestation by wood-consuming insects, and the length of time the branch has been dead.

Broken branches are branches that have experienced structural failure. They may remain partially attached at the point of breakage, or they may have completely detached and started to fall. Branches that are broken and lodged in the crown of the tree are called hangers or lodged branches. The likelihood that the branch will continue its fall depends upon how it is being held and if the branch is decaying. The likelihood of failure in a three-year time frame of most hangers is considered *probable* or *imminent*.

Dead roots can be much more difficult to identify, but they can cause significant loss of stability. The decay rate of dead roots depends on tree and fungal species, climate, soil type, and tree health. Sometimes roots deteriorate very quickly (within one year), while other dead roots may provide structural support for much longer.

Fire-Damaged Trees

Trees that have been killed or damaged by fire vary significantly in their short- and long-term likelihood of failure. Factors affecting likelihood of failure include tree species, tree condition before and after the fire, and the severity of the fire damage above and below ground. Some thick-barked tree species have evolved to endure fires, while other species are more easily damaged. The fire intensity, duration, and location (low to ground, underground, or in the treetops) can affect the amount of damage. The time elapsed since the fire can be an important factor. Because possible tree damage can be internal or even below ground, assessment of the likelihood of failure can be difficult. Specialized training and experience can be valuable for assessing fire-damaged trees. Sometimes, a Level 3 assessment may be needed to determine the severity of internal damage or root damage.

Branch Defects and Conditions

In general, branch attachments are strongest when the parent branch is at least twice the diameter of the subordinate branch, the branch union is U-shaped, and there is adequate wood to securely hold the branch in place. Codominant stems with included bark and adventitious branches can represent potential weaknesses, especially when combined with other conditions that can increase the likelihood of failure.

Various branch defects and conditions are discussed in this section. In some cases, guidance for categorizing the likelihood of failure is given. A three-year time frame is used in these examples for consistency and comparison, but tree risk assessors and managers should select a time frame that is appropriate for the situation.

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Wes Kocher

Figure 6.2 In some species, dead branches may remain mechanically stable for many years after death. The likelihood of failure rating for dead branches within a three-year time frame ranges from *possible* to *imminent*, depending upon species, branch weight, type and extent of decay, infestation by wood-consuming insects, and length of time that the branch has been dead. In this case, the assessor rated likelihood of failure of the dead branch *probable* in a one-year time frame.

Adventitious Branches and Epicormic Shoots

Strong branch attachments form when branch and trunk wood develop together over time. **Adventitious branches**, such as **epicormic shoots** or water sprouts, are often produced after storm-related branch breakage, lion-tail pruning, or topping. If these branches are attached near a cut or broken branch end, decay developing from the opening may reduce the load-bearing capacity of the attachment over time. Within a three-year time frame, the following guidelines may be helpful. If decay is not present, likelihood of failure in adventitious branches may be considered *improbable* to *possible*. If decay is present, the likelihood of failure may be considered *possible* to *probable*, depending upon load and weight distribution. If significant new holding wood has developed, the likelihood of failure may be reduced to *possible* or *improbable*.

E. Thomas Smiley

Figure 6.3 Broken branches are branches that have experienced a structural failure. The likelihood of failure of most hanging branches (hangers) is *imminent* or *probable* within a three-year time. This hanger was assessed as *imminent*.

Codominant Stems and Branches

Two stems or branches that are approximately equal in diameter and arise from the same location are called **codominant** stems. Typically, strong branch attachments develop when the size of the branch is less than one-half the diameter of the parent stem. When the diameters of the branch and parent stem are similar, the attachment may be weaker. Stem orientation, weight distribution, response growth, and branch configuration will affect stress at the union, making failure more or less likely. Not all codominant stems have an increased likelihood of failure.

The likelihood of failure is also affected by the shape of the union and by the presence or absence of included bark. The shape of the union can provide additional information about union strength. Stems that divide in a gentle U-shape tend to be stronger than those with a sharper V-shape. V-shaped attachments are often associated with included bark that tends to reduce load-bearing capacity. Likelihood

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Figure 6.4 Adventitious branches, such as epicormic shoots or watersprouts, are weakly attached in the short term because minimal wood has formed to hold the branch in place. If these branches are attached near a cut or broken branch end, decay developing from the opening may further reduce the strength of the attachment over time.

of failure of codominant stems with a V-shape within three years is often considered *improbable* to *probable*. Failure of U-shaped unions is usually *improbable*.

In some tropical species (e.g., *Angsana* [*Pterocarpus indicus*]), the presence of adventitious roots at a codominant stem union may indicate a crack and should be investigated further.

Included bark is bark that is embedded between a branch and its parent stem, or between codominant stems, decreases the load-bearing capacity of the attachment. The likelihood of failure of branches with included bark largely depends on the extent of bark inclusion and the loads experienced by the branch from wind, ice, snow, and other sources. For many species, failure of codominant stems with included bark may be considered *possible* to *probable* within a three-year time frame. If there is significant decay in or near the union, the likelihood of failure can be *probable* or *imminent*, depending upon loads and weight distribution. The presence of response growth at the union may reduce the likelihood of failure. The presence of cracks below the union may indicate an increased likelihood of failure.

Julian A. Dunster

Figure 6.5 Two stems or branches that are approximately equal in diameter and arise from the same location are called codominant. When the diameters of the branch and parent stem are similar, the attachment may be weak, especially if there is included bark, decay, or a crack present. The likelihood of failure of this codominant branch configuration was rated as *possible* for a three-year time frame.

When considering pruning of one side of a codominant stem, there is no branch protection zone within the tree and no branch collar at the base, so a larger-than-normal column of decay may develop after pruning. This may be a consideration when weighing the trade-offs between stem reduction or removal, installing a support system, or retaining and accepting the associated risk.

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Julian A. Dunster

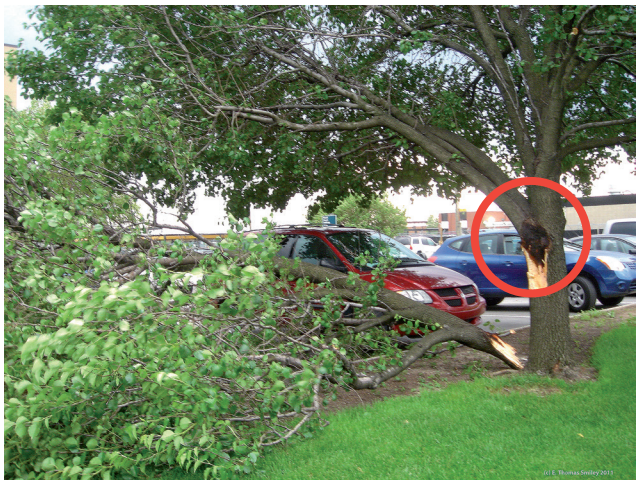
Figure 6.6 Likelihood of failure of a codominant stem with a V-shape (acute angle), as seen in this tree, is often considered *improbable* to *probable* within a three-year time frame. In this case, the assessor rated it as *possible* within a three-year time frame.

E. Thomas Smiley

Figure 6.7 Failure of U-shaped unions, as seen in this tree, is often considered *improbable* to *possible* within a three-year time frame.

Multiple Branches Originating at One Point

When several (three or more) branches originate from the same place on the stem, the branches tend to be more weakly attached than single branches of the same size. Often there is insufficient space for holding wood to develop around each branch when multiple branches arise at one point. For some species that tend to fail at this point, the likelihood of branch failure may be considered *possible* to *probable* for a three-year time frame, depending upon load, weight distribution, and shape of branch union. The likelihood of failure for more resilient species may be considered *improbable* to *possible*. If decay is also present near the point of multiple branch attachments, the likelihood of failure is increased.



E. Thomas Smiley

Figure 6.8 Included bark is bark that is embedded between a branch and its parent stem, or between codominant stems. It decreases the strength of the attachment.

Overextended Branches

Overextended branches (protruding branches) are those that are unusually long or extend outside the normal crown area. Branches outside of the normal crown sometimes experience higher loads during strong winds, freezing rain, or snowstorms and may be more likely to fail in these conditions. The word "overextended" does not imply that a branch is necessarily too long or too heavy.

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Figure 6.9 When several branches originate from the same place on the stem, as in this previously topped tree, there may not be enough space for sufficient wood to develop around each branch to provide adequate support. The likelihood of one of these branches failing in a five-year time frame was rated as *probable*.

Sudden Branch Drop

Sudden branch drop (SBD), also known as summer branch drop, is the sudden, unanticipated failure of a tree branch during calm conditions and warm temperatures. It is often associated with long, horizontal branches with little or no discernable defect.

At this time, it is not possible to predict SBD failures.

Trunk Defects and Conditions

When tree trunks fail, failure is often the result of a loss of cross-sectional area of the stem from decay, cankers, wood consuming insects, or wounds. Solid stems can fail when the load on the stem is greater than its load bearing capacity, such as when the tree experiences extreme weather conditions, the tree has recently been exposed to higher wind velocities than typical, the wind is from a different direction than normal, or there are structural weaknesses in the crown.

In this section, many types of trunk defects and conditions that could affect a tree's likelihood of failure are discussed. In some cases, guidance for categorizing the likelihood of failure is given. A three-year time frame is used in these examples for consistency and comparison, but tree risk assessors and managers should select a time frame that is appropriate for the situation.

Nelda Matheny

Figure 6.10 Overextended, protruding branches outside of the normal crown may experience higher loads during strong winds, freezing rain, or snowstorms, and are more likely to fail in these conditions. A tree risk assessor rated the likelihood of failure of this overextended branch to be *possible* in a two-year time frame.

Missing or Decayed Wood

Missing wood refers to anything that decreases the cross-sectional area of a trunk or branch. This can be the result of mechanical injuries, termites, cankers, or decay. Wood **decay** is the long-term process of wood degradation by microorganisms. The presence of a large proportion of decayed wood or missing wood may reduce the load-bearing capacity of a tree. Decay fungi may reduce wood strength well

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in advance of the development of internal cavities. However, the mere presence of decay does not indicate that the tree has been significantly weakened.

Decay is often difficult to detect, and, once detected, it is not always easy to assess its extent or significance to likelihood of failure. In many cases, the tree was wounded years before the assessment visit. Decay fungi can infect wounds and decompose wood slowly over decades, or rapidly over a few years. Many fungal pathogens have characteristic patterns of decay, and to some extent, knowing the pathogen and how it develops can help to determine the likely internal conditions.

Decay fungi may reduce wood strength well in advance of the appearance of fruiting bodies or the development of internal voids. The tree risk assessor should therefore look for indicators of decay during their assessment. There are two categories of decay indicators: definite indicators and potential indicators. Potential indicators point to the possibility that decay is present, whereas definite indicators occur only when decay is present.

The most common **definite indicators** of decay or missing wood are:

- Cavity openings, nesting holes, and other voids or openings on the outside of the tree
- Fungal fruiting structures, such as mushrooms, conks, or brackets, that are attached to the tree
- Ants (especially carpenter ants), bees, or animals inhabiting or emerging from cavities, cracks, or other defects
- Termite emergence from internal nests or tunnels

The most common **potential indicators** of decay, loss of wood strength or missing wood are:

- The presence of wounds or branch stubs that may allow decay fungi to enter the tree
- Response growth patterns, such as swelling, bulges, or ridges that form as the tree compensates for wood strength loss
- Cracks or seams
- Oozing through the bark
- Dead or loosely attached bark, or bark with abnormal patterns or colors
- Sunken areas in the bark
- Termite trails on trunks and/or branches

To assess the tree, the tree risk assessor may attempt to estimate the extent of internal decay by interpreting the location and condition of decay using indicators of decay and the Compartmentalization of Decay in Trees (CODIT) model. External indicators of decay alone may not provide an accurate picture.

Striking the tree with a mallet and listening for tonal differences may aid in estimating the size and location of internal hollows. When a tree risk assessor desires substantially more information on the extent of decay to assess the likelihood of failure, an appropriate advanced assessment (Level 3) may be recommended.

The likelihood of failure associated with decay depends upon the relative amount and location of decay within the tree, the tree species and size, lean, weight distribution, exposure to loads, and response growth.

Cavities and Other Openings

Cavities are openings into the wood of trees that occur on branches, trunks, and roots. They are a definite indicator of decay. It is not unusual to find trunks and branches with cavities, but their presence is not an automatic reason to condemn the tree.

Cavities are often used by wildlife as a habitat. The fact that birds or small mammals are using a cavity is an initial indicator that the cavity may be extensive. Most cavities in use as animal habitat tend to be dry inside. A wet cavity collects rainwater either from direct entry into the cavity opening or from seepage coming down through a column of decay above the cavity opening. Wet cavities can be more serious because the decay column may be connected to one or more other openings higher up in the tree and likelihood of failure may be increased.

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Figure 6.11 Cavities are common at locations of past injury that created a place for decay fungi to enter the tree. Examine cavities to determine their extent, whether the decay is still expanding, and whether the tree is producing response growth. Based on a five-year time frame, the assessor rated the likelihood of failure of the trunk of this tree as *probable*.

Sounding the wood around the cavity with a mallet may provide information on the extent of the cavity. The extent of a cavity may also be estimated by probing. Probing is the insertion of a small diameter rod, stick, or stiff wire into a cavity or crack to determine its depth. Care should be taken when probing, and assessors should avoid putting their hand inside a cavity. Check to make sure that the cavity is not occupied by wildlife, such as squirrels, raccoons, snakes, scorpions, or spiders. In some cases, a more advanced assessment will be required to accurately define the extent of the cavity.

Sapwood Decay or Damage

Loss or degradation of sapwood due to decay, cankers, or mechanical damage can contribute to tree failure. Sapwood loss is considered more important to stem strength than heartwood loss, because wood in the outer part of the stem contributes substantially more to the load-bearing capacity of a stem than wood closer to the pith. Examples of sapwood damage are certain types of cankers, mechanical injury, animal activity, and **sapwood decay**.

If excessive amounts of sapwood are missing from a tree due to injury or cankers, the tree will be more likely to fail. If a tree has both external wood loss and internal decay, the likelihood of failure can be greatly increased because the tree's ability to compensate for strength loss by increasing diameter growth is limited. The likelihood of failure depends on several factors, including the amount and location of sapwood that is missing, the amount and type of internal decay, tree size, lean, weight distribution, and exposure to loads.

Cankers

Cankers are areas of dead or dying wood, cambium, or bark caused by diseases. Perennial canker-causing organisms (target cankers) infect the tree through a bark wound. They tend to grow slowly during dormancy and are then surrounded by a new callus roll during the active growing season. Diffuse cankers are shallow and tend to advance more rapidly in the bark, often overwhelming the tree's defensive abilities. The bark at the margins may be discolored. Canker rots start as cankers of the bark and then progress into the stem, decaying wood as they progress.

If there is a lack of new wood growth or significant loss of sapwood, cankers may affect the likelihood of failure. Large canker faces may engulf substantial amounts of the trunk. As a guideline, if more than one-third of the circumference is affected, the likelihood of failure may be *probable* within a three-year time frame, depending upon species, exposure, and whether or not decay is also present. If decay is present, the likelihood of failure within three years may also be *probable*.

Bulges

Bulges are pronounced areas of growth whose shape does not match the rest of the tree. Bulges may be a

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type of response growth that can occur in response to internal decay, cracks, and wounds. They are sometimes associated with localized compression failure where the weight of the tree is crushing the trunk downward. This occurs when the trunk is hollow and the remaining shell wall thickness is thin.

Bulges are common at the root collar and often indicate one of two issues: (1) loss of wood due to root decay moving into the lower trunk and triggering response growth to thicken the remaining shell wall around the decay, or (2) a response to contact stress where the tree has grown against and around an object—for example, a pipe, old railing, or rock.

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Figure 6.12 A pronounced bulge associated with codominant stems is formed when the stems have reached a point where inward growth is no longer possible (no space to grow), and new tissue is formed on opposite sides of the two stems.

A particular form of bulge is seen on either side of codominant stems. Once the stems have reached a point where there is no more space to grow inward, new tissue often forms on either side, forming a pronounced rib or bulge spanning the base of the two stems. The bulges are seen at opposite sides of the two stems. There is usually an area of included bark between the stems, and decay may be present. In advanced growth stages, it is common to see cracks in these bulges because the two stems have moved away from each other. This area of additional wood growth is a high-stress area, and failure is common at this point.

A trunk or branch that has an elliptical shape (ribs or bulges on opposite sides) may have a shear plane crack through the wood, with new growth forming around the cracks. Or it could be the point below two codominant stems where the new wood has grown over the base of the two stems to cover the crack and included bark underneath.

Occasionally, bulges form at branch attachments, either on the top or the underside. This type of bulge may indicate an internal problem such as decay or cracks. If the bulges are on the horizontal plane, it might be that gravity is overtaking the strength of the attachment point (a horizontal shear plane crack is developing), and new supporting wood is being added. Bulges on the top and bottom could be a vertical crack that developed in an extreme wind (caused by lateral motion). As with all other bulges, an advanced assessment may be required to assess the severity of the defect or condition.

Ridges

Ridges can sometimes be seen on trunks, branches, or below branch unions. They are often more apparent on smooth-barked trees. Sometimes these growth patterns are normal for the species. They could also be formed in response to compression or phloem feeding insect borers. Of greater concern are ridges formed in response to buckling, cracks, or twisting of the wood. An advanced assessment may be necessary to determine if decay is present beneath the symptoms.

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Figure 6.13 Response growth and the effects of gravity can result in ridges on curved trunks or branches. They often are more apparent on smooth-barked trees. The likelihood of failure for these trees was rated as *improbable* within three years.

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Figure 6.14 Cracks are a separation of wood fibers. They are the result of a localized failure caused by excessive compression, tension, or torsion.

Cracks

Cracks are separations in the wood in either a longitudinal direction (radial direction, in the plane of ray cells) or transverse direction (across the stem). Longitudinal branch cracks (also called shear plane cracks or neutral plane failures) most commonly occur when branches are overloaded by freezing rain or snow.

Cracks also occur when stems experience large torsional stresses or are below codominant unions that are splitting apart. Because internal decay may weaken a stem, longitudinal cracks may be associated with the presence of decay. Trunks or branches with cracks that extend completely through the stem or branch or cracks above cavity openings that have partially failed are at risk of complete failure.

Where guidance for categorizing the likelihood of failure is given, a three-year time frame is used for consistency and comparison. Tree risk assessors and managers should select a time frame that is appropriate for the situation.

Transverse cracks indicate that the fibers in the wood have pulled apart or buckled. They occur when wood is under excessive tensile or compressive stresses. Cracks are a sign of localized failure and may indicate that tree or branch failure ranges from *possible* to *imminent* within a three-year time frame, depending upon the type of crack, expected loads, and the observed tree response.

The wood behind cracks may be sound, decayed, or completely missing. A crack can:

- start at the surface and penetrate into the wood
- start inside the wood and radiate outward
- extend all the way through the branch, stem, or root

Typical tree response to a crack through the bark is to produce woundwood along the margins. Over time this response growth may roll into the opening. The woundwood may eventually meet and form ribs. If the cambium layers from the two sides merge, they can become a seam and the crack will be completely enclosed.

When assessing cracks, try to determine the following:

- Extent of the crack, both length and depth
- Presence or absence of decay
- Presence or absence of response growth
- Cause of the crack

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Jon Banks

Jon Banks

Figure 6.15 Cracks can occur when stems or branches are torsionally stressed. The left photo was taken during the winter; the tree failed during a storm after foliage emerged (right).

Cracks that are fresh and associated with decay greatly increase the likelihood of failure, sometimes to *imminent*. Cracks that penetrate all the way through a stem with no decay will often increase the likelihood of failure to *probable* within three years. Cracks that have woundwood surrounding them, including the peak of the cracks, will have a slightly lower likelihood of failure. Transverse cracks that occur across the short axis of the root, trunk, or branch are symptomatic of wood that has advanced decay. Likelihood of failure within three years is *probable* to *imminent*.

Shear Plane Cracks

Stem or branch cracks going through the pith or center of the growth rings near the center of the long axis (vertically in trunks, or along the length of branches) are known as **shear plane cracks**, neutral plane failures, or hazard beams. They occur at the transition zone between the opposing forces of tension and compression when the part is being bent. If a crack is obvious only on one side of the cross section, it may be a result of torsional forces. If the shear plane crack is visible on both sides, 180° apart, the entire component (branch, trunk, or root) has split. Shear plane cracks can result from bending forces caused when branches or trunks that are overloaded, typically by snow or ice loads. In branches, they often follow the curve of the branch.

If the separation does not result in complete failure, there will be two pieces of wood acting independently of each other, and the overall strength of the component (trunk, branch, or root) is decreased. If the forces that created the crack do not recur, the tree may develop response growth, typically seen as woundwood growing along the edges of the crack.

Failure of trunks or branches from shear plane cracks is very difficult to predict. Once they occur, the likelihood of failure of the whole branch within three years may range from *improbable* to *probable*.

E. Thomas Smiley

Figure 6.16 Cracks located along or close to the center of the long axis (vertically in trunks, or along the length of branches) are also known as shear plane cracks, neutral plane failures, or hazard beams. They occur at the transition zone between the opposing stresses of tension and compression when the part is loaded. Based on a five-year time frame, the assessor rated the likelihood of failure (and falling) of this branch as *probable*.

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CASE STUDY

Assessment of a Shear Plane Crack

Assignment: Basic assessment of trees on the grounds of a stately home.

Time Frame: Five years.

Targets and Site: Targets include landscape maintenance staff with *rare* occupancy. All trees are partially protected from wind exposure. No soil factors or site changes were noted.

Tree Conditions: A yew (*Taxus* sp.) tree has a 12 in (30 cm) diameter lateral branch, 3 ft (1 m) above the ground with a shear plane crack about 2 ft (61 cm) long. Response growth has developed along both edges of the crack.

Analysis: Although the defect is well defined, the likelihood of impact is *very low*, and the likelihood of failure is *improbable*. This combined likelihood of failure and impact is *unlikely*, which makes the level of risk *low*, no matter what the consequences of failure rating is. The branch supports a large amount of foliage that is contributing to the overall energy balance of the tree, and removal would leave a large wound. The crack has not been extending, and the tree is compensating for it.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Mitigation Options: 1) Retain and reassess. 2) Prune to reduce branch weight.

Reporting: A written report was submitted to the property owner.

The property owner decided to have the length of the branch reduced.

Photo by Julian A. Dunster

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Figure 6.17 Shear plane cracks can result from bending forces on branches or trunks that are being overloaded by gravity, snow, ice, or wind. In branches, they sometimes occur at a curve in the branch. Some shear plane cracks close and develop response growth. In this case, the likelihood of further failure of this branch within one year was rated as *improbable*.

Cracks and Decay

Sometimes, cracks are formed in association with internal decay. Cracks can result when the nondecayed wood around a column of internal decay fails in compression or torsion. Cracks may form on one side or multiple sides of a trunk or branch. Torsional cracks often spiral with the wood grain. Cracks in the bark or shallow wood cracks that do not penetrate deeply into the wood may not represent a serious structural problem.

Cracks on multiple sides suggest advanced columns of decay and a trunk that is buckling or twisting under load. Picture a barrel made of wood staves that is being squashed. As the barrel is squashed, the staves buckle outward, and cracks appear in between each stave. In these cases, the likelihood of failure within a three-year time frame may be considered *probable* to *imminent*.

The depth of the crack and presence of any surrounding cavity can sometimes be determined by probing through the crack opening. Extensive decay and recent cracks often lead to a likelihood rating of *imminent*.

Transverse Cracks

Horizontal (transverse) cracks on a tree trunk are not common but are more serious than vertical cracks. An open horizontal crack may be investigated by probing. Often horizontal cracks are categorized as *imminent* likelihood of failure.

Seams

Seams are lines formed where two edges of bark meet from adjacent stems, or at a crack or wound. The likelihood of failure within a three-year time frame at a seam is generally considered *improbable* to *possible* if there is solid wood behind the seam. However, sometimes the seam covers decay or old

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The Bartlett Tree Expert Company

Figure 6.18 Horizontal (transverse) cracks on a tree trunk are not common but are more serious than vertical cracks. Often, horizontal cracks are categorized as *imminent* likelihood of failure. The photo on the right shows a failure that occurred within two weeks of the tree risk assessment (left).

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Factors That Increase the Likelihood of Failure Rating for Decayed Branches and Trunks

- Multiple pockets of decay
- Significant end weight
- Lack of branching needed for damping
- Tree species known to have weak wood or allow rapid advancement of decay
- Decay fungi known to advance rapidly

Factors That Decrease the Likelihood of Failure Rating for Decayed Branches and Trunks

- Significant amounts of response growth
- Small crowns
- Low wind exposure
- Decay-resistant/strong compartmentalizing tree species
- Decay fungi species known to advance slowly

Julian A. Dunster

Julian A. Dunster

Figure 6.19 (a) Seams are pronounced lines or zones of response growth, or lines of growth that have curved inward. They are typically associated with a wound or a crack. (b) If the seam conceals a wound, there may be an area of decay and *possible* strength loss behind it that can increase likelihood of failure.

cracks. If a probe can be inserted between the seam edges, there could be a column of decay. A cavity behind a crack may require further investigation to determine its extent and implications for likelihood of failure. Depending upon the extent of decay, exposure to loads, and weight distribution, failure at seams covering cracks or decay may be considered *possible* to *probable* within the next three years..

Ribs

Ribs are longitudinal bulges of response growth that can indicate an internal crack and/or decay. Over time, the response growth may cover the weak area, leaving an abnormal bark pattern, rib, or bulge. If the rib has a sharp edge, the crack may be quite close to the surface. Ribs that contain active cracks should be evaluated similarly to other cracks. If the tree has fully closed the crack with new wood so that there is more of a blunted edge, then the crack may be buried inside the trunk or branch. Ribs covering over closed cracks should be evaluated similarly to seams. Ribs can run in a spiral manner up the trunk and may be discontinuous. This suggests a torsional crack inside. Many species have a spiral grain that predisposes them to spiral ribs.

Growth cracks (striations) that form in the outer bark during periods of rapid trunk growth, such as

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Figure 6.20 (a) Response growth resulting from a crack may create a rib. (b and c) If there is decay behind a rib, there can be an increased likelihood of failure.

in early summer or midsummer, or during the rainy season in tropical regions, are not considered structural defects.

Frost Cracks and Freeze–Thaw Cracks

Frost cracks and **freeze–thaw cracks** result from exposure to sun during cold temperatures. Frost cracks can appear on any side of the trunk or branch, while freeze–thaw cracks are especially common on the south and west sides of the trunk (in the Northern Hemisphere) or the upper surface of the branches. Freeze–thaw cracks are common in climates where extreme cold periods are followed by rapid warming in the sun. In these cases, the core of the wood is frozen, but the external surface warms up and creates a freeze–thaw expansion sequence that cracks the outer wood surface. Frost and freeze–thaw cracks tend to have pronounced ribs and evidence of annual or periodic failure of the new wood. Shallow surface cracks are less significant than cracks that penetrate deep into the structure (potential shear plane cracks). The likelihood of failure within a three-year time frame of these types of crack is typically *improbable* to *possible*.

E. Thomas Smiley

Figure 6.21 An uncorrected lean where the trunk leans at a consistent angle along its length.

Tree Architecture

Tree architecture or form, including tree growth and branching characteristics, can affect how a tree moves in the wind, how the load of the crown is distributed, and the tree's stability. Problems with structural defects become more significant when tree architectural abnormalities are present. Where guidance for categorizing the likelihood of failure is given, a three-year time frame is used for consistency and comparison. Tree risk assessors and managers should select a time frame that is appropriate for the situation.

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Lean

Lean is the angle of the trunk measured from vertical. Trees can lean naturally as they grow toward light and away from neighboring trees or structures, and in locations with a strong prevailing wind. This is not necessarily a defect because the tree has responded to existing growing conditions. However, when an excessive load or structural defect causes a tree to lean, it may create an unstable situation because the weight of the stem and crown is offset from vertical, which creates a bending moment. Trees can add response growth to compensate for the bending moment, which reduces likelihood of failure. However, trees with uncorrected leans and leaning trees on slopes with saturated or unstable soils may not be able to compensate in the short term and are often less stable than straight trees or those with corrected leans.

Trees may also lean because of a partial failure of the lower stem or roots, or soil conditions that allow excessive root movement. Trees that increase in lean over a short time period are of concern and should be examined promptly. Lifting of the soil on the side of the tree opposite the direction of lean, or a depression on the side of the lean, may indicate that the roots or soil are failing. Lean angle can be determined using several means, including the use of a

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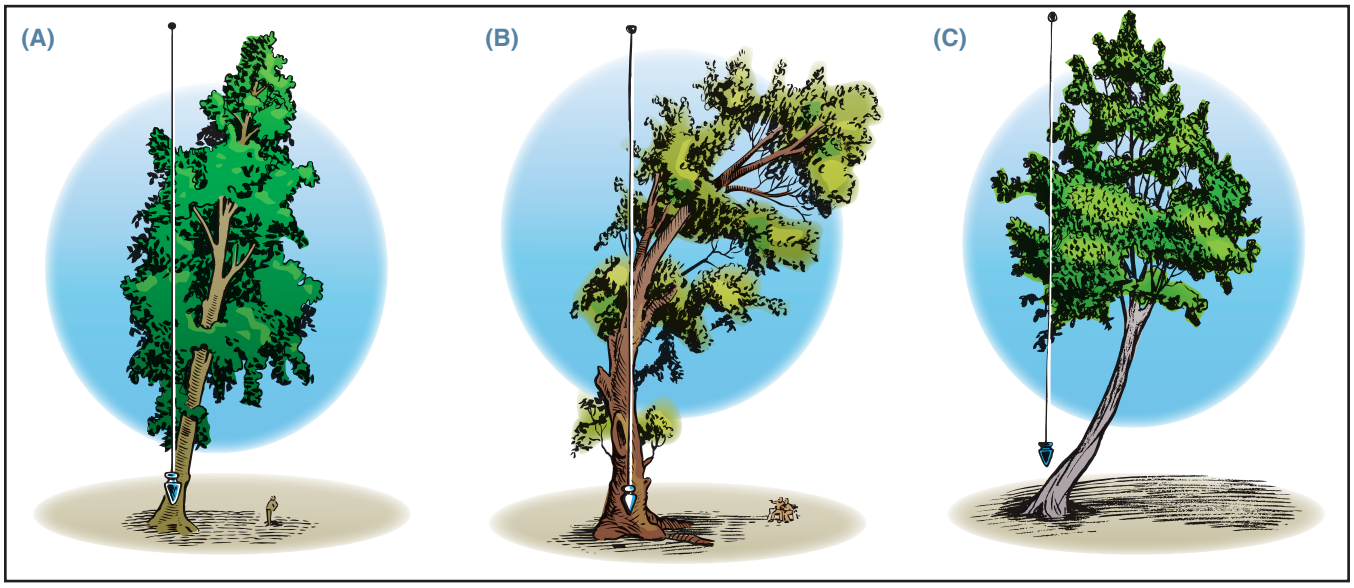
Figure 6.22 Corrected leans where the lower trunk is leaning and the upper trunk is more vertical.



Bryan Kotwica

Figure 6.23 Lean is the angle of the trunk measured from vertical. The pattern of tree lean can affect the likelihood of failure. Illustrated here from left to right are (A) a straight lean, (B) a bow, and (C) a corrected lean or sweep.

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CASE STUDY

Tree Lean and Likelihood of Failure

Assignment: The assessor was hired by a homeowner in an established residential area to perform a basic tree risk assessment on a row of trees that is at the back of their yard, next to the neighbor's house.

Time frame: Two years

Targets and Site: Three Lawson cypress (*Chamaecyparis lawsoniana*) at one end of the row of mature trees were recently removed after storm damage. The target of concern was the house on the adjacent lot.

Conditions: The bowed Lawson cypress which was formerly protected by nearby trees, was leaning over the adjacent house. The tree had little taper and a relatively low live crown ratio.

Analysis: Removal of the three trees at the end of the row allowed one of the remaining trees to lean into the space where there were previously other trees. The likelihood of failure was rated as *probable*, and likelihood of impacting the house was considered *high*. Accordingly, the likelihood of failure and impact was *likely*. The consequences of failure were categorized as *significant*, yielding a risk rating of *high*. Adjacent trees could have similar problems in the future because of their new exposure.

Mitigation: Remove the bowed tree and reassess the remaining trees on an annual basis for change in lean, bowing, and uprooting due to the new exposure.

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Reporting: A written report was submitted to the tree owner who is the tree risk manager. The tree risk manager had the leaning tree removed.

Matrix 1: Likelihood Matrix
The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix
Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photo by Julian A. Dunster

digital level, sequential photographs, or 3-D scans. The residual stability of a leaning tree may be determined by load tests. The likelihood of failure of a recently leaning tree within a three-year time frame is often *probable* to *imminent*.

Corrected Leans

Corrected leans (sweeps) are characterized by a leaning lower trunk and a top that is more upright. Trees may develop this form when growing at the edge of a group. Such trees are stable under normal conditions but may be less stable than straight trees under additional loads. A sweep also may develop when a tree leans due to partial failure and response growth has turned the crown upright. The likelihood of failure increases as the lower trunk angle and crown weight increase. Trees with corrected leans are often considered to have a likelihood of failure from *improbable* to *possible* within a three-year time frame.

Bows

Bows are leans characterized by the top of the tree bending over more than the lower trunk, creating a curve. Trees may develop this form when growing at the edge of a group or next to structures. Such trees are stable under normal conditions but are often less stable than straight trees under additional loads.

Bows also may occur under snow or ice loading or during strong winds. Some trees never recover from or respond to this type of damage. Bowed trees also

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should be examined for cracks. The likelihood of bowed tree failure within a three-year time frame may be *possible* to *probable* if the tree has not increased the stem diameter by response growth. If cracks are present, the likelihood of failure may be *probable* to *imminent* if the tree is subjected to loads from wind, snow, or freezing rain.

One-Sided or Unbalanced Crowns

Ideally, branches are evenly distributed vertically and horizontally around the trunk. Trees with even branch distribution tend to distribute the loads evenly along the trunk, reducing the likelihood of trunk and root failure as compared to trees with uneven branch distribution. A tree may have most of its branches on one side if it is growing close to another tree or structure, has uneven crown dieback, is damaged by a storm, or has been pruned in that manner. In most cases, trees develop response growth to support the asymmetric crown. But asymmetric crowns can increase the likelihood of failure because they may subject the trunk to greater torsional stress. When other problems are present, such as compromised root anchorage, an asymmetric crown can also increase the likelihood of failure.

Jim Clark

Figure 6.24 An unbalanced crown where the majority of branches are on one side of the crown.

Live Crown Ratio, Taper, and Height/Diameter Ratio

Taper is the change in diameter over the length of trunks, branches, and roots. The degree of taper is a reflection of the tree's ability to produce sufficient energy to create a uniform growth increment along the entire trunk or branch. Trees with small crowns and tall trunks are less likely to have uniform growth increments than trees of the same height but with larger crowns because the amount of energy produced is a function of the amount of living crown.

Live Crown Ratio

The ratio of the vertical extent (height) of the live crown to the height of the entire tree is the **live crown ratio** (LCR). LCR is affected by growing conditions, pruning history, previous branch failures, and natural branch shedding. Low LCR most commonly develops naturally where trees are growing in dense groups, but it can also be created by crown raising. Low LCR can be a condition of concern, especially if the tree originally developed in forest conditions and was recently exposed to stronger wind conditions. For some tropical tree genera with extremely hard wood, a low LCR may not necessarily be a cause for concern. LCR is rarely used by itself to classify likelihood of failure.

Taper (Slenderness)

Taper is important for even distribution of mechanical stress. The degree of taper can be calculated by dividing tree height or branch length by the trunk or branch diameter (H/D). The same units are used for both height and diameter (feet or meters). Accurate measurements are essential when determining both height or length and diameter because minor errors can have a major impact on the ratio. When H/D is large (that is, the tree or

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branch is very slender for its height), there may be an increased likelihood of failure. Reported critical H/D values vary from 50:1 to 90:1. Because of the size of this range, H/D ratio is rarely used by itself to classify likelihood of failure.

The amount of stem taper is often related to LCR. Lower LCRs are associated with less taper. Trees that were originally grown in forest conditions, and recently exposed to more wind because of the removal of adjacent trees, are of greatest concern. Conversely, taper is less of a concern for trees in an undisturbed forested area where individual trees are surrounded by other trees and are therefore protected from the effects of the wind. Additionally, due to palms' unique form and lack of true secondary growth, taper concerns do not apply to them.

Root Problems

When roots are severed, decayed, broken, undermined, or restricted, they provide less anchorage. Other root-related problems, including buried buttress roots and stem-girdling roots, can affect root decay or response growth, which, in turn, affects tree stability. In addition to structural problems with roots, some soils, especially when saturated, allow excessive movement of structurally sound roots, which can reduce stability.

Root problems often develop in the nursery and are not corrected at the time of planting. Because most roots are not visible, root defects are often difficult to detect. Soil and site conditions around the tree can sometimes provide information about changes that have damaged the root system or affected soil strength. Symptoms to look for include the following:

- **Dead, decayed, or missing roots.** These sometimes can be identified by a cavity in the root collar, a canker that extends to the soil line, or a visibly pruned or broken root stub. The likelihood of failure increases with the number of roots that have been damaged and with the number of decayed roots. The likelihood of failure can be decreased by the presence of response growth.
- **Fungal fruiting structures.** Fungal fruiting structures attached to roots or the root collar area are definite indicators of root decay. Root decay assessment is an advanced assessment technique that may be recommended or conducted when definite indicators of decay are present.

E. Thomas Smiley

Figure 6.25 Severing major, structural roots will decrease the stability of a tree. The likelihood of failure increases with the number of roots cut and decreases with the distance from the trunk. The likelihood of windthrow within three years for this tree was rated as *probable*.

E. Thomas Smiley

Figure 6.26 Fused roots may indicate response growth to root decay.

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Julian A. Dunster

Figure 6.27 Larger-than-normal flare at the base of the tree may indicate that root decay is present. This condition is a form of response growth that may indicate the presence of defects, but it also can add strength to resist bending. Failure of this tree within a three-year time frame was rated as *possible*, with an advanced assessment recommended.

E. Thomas Smiley

Figure 6.28 For most open-grown tree species, if the buttress roots are not visible, then there is soil against the trunk of the tree, which may accelerate sapwood or heartwood decay. The tree was recommended for an advanced assessment of the root collar area.

- **Dead or detached bark.** This may indicate that the cambium is dead, and the wood beneath may be damaged, decayed, or nonfunctional. If bark is easily removed, the sapwood can be examined for the presence of fungal mycelia, fans, and rhizomorphs, all of which are definite indicators of decay.
- **Abnormal root flares or fused buttress roots.** A larger than normal flare for the species at the base of the tree and fusing together of buttress roots may indicate that root decay is present. Both of these conditions are response growth that may indicate the presence of defects, but they also add strength to resist bending and aid stability. Large basal flare can also develop in some species that are growing on shallow soil.
- **Buried root collar.** If the tree's root flare or buttress roots are not visible, there may be soil or other material against the trunk. Soil against the trunk may result in accelerated decay development.
- **Basal trunk decay.** Decay in the base of the tree may indicate root decay, because some basal decay fungi start as root decay fungi.
- **Stem girdling.** When there is a root, strap, chain, rope, rock, concrete, or other material tightly against the lower trunk or buttress roots, growth and response growth can be severely limited. This can lead to health and stability problems.
- **Wounded roots.** The sapwood on the upper surface of roots tends to compartmentalize well when damaged by lawn mowers or trimmers. However, decay may develop in these wounds if the damage is recurring or severe, if the damage extends into the heartwood, or if there is a decline in tree health.
- **Oozing.** Oozing from the lower trunk and buttress roots is sometimes associated with root disease. Root disease may impact tree health, such as from a *Phytophthora* infection, or may affect stability, as with an extensive *Armillaria* infection.
- **Adventitious roots.** These develop when the trunk is buried or there is a loss in root function. They can serve as an indicator of, and as compensation for, root health problems.

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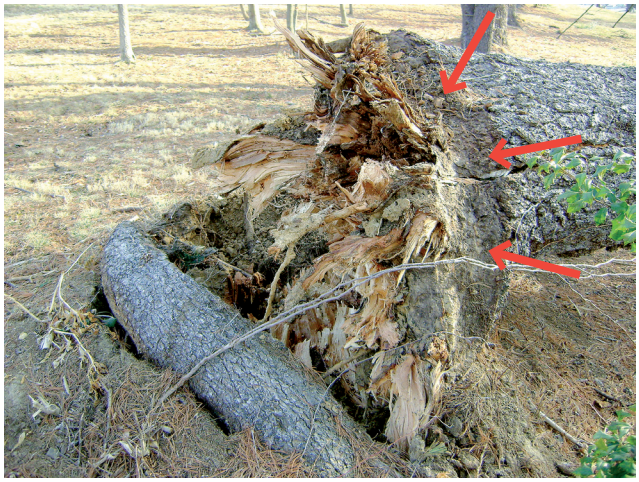

Adam Braaten

Figure 6.29 Flat areas at the trunk flare may indicate missing roots, girdling roots, or root growth obstructions such as rocks or underground infrastructure. This tree had a very large stem-girdling root, which contributed to tree failure.

Tree and site conditions that can indicate the potential for root-related structural problems:

- **Crown dieback, thinning, or decline.** Root damage or decay can restrict the movement of water and nutrients into the crown, which can lead to crown dieback, thinning, or decline. This may take many years to become apparent after root damage.
- **Evidence of trenching, grade changes, compaction, or other root or soil disturbance.** Such evidence may be seen as depressed lines on the soil surface, sharp drop-offs, or other changes in levels; areas that lack vegetation; or mounds of soil. New pavement or foundation near a tree can also indicate that roots have been damaged.
- **Soil mounding or cracking.** This is sometimes associated with a leaning trunk and may indicate that the roots are lifting the soil. Dry soil may also have cracks that are unrelated to tree movement.
- **Restricted soil space.** If the rooting area is restricted by structures, soil compaction, impermeable soil layers, excessive soil moisture, or a high water table, the root system may not develop well enough to adequately anchor the tree.
- **Excessive soil moisture.** If the soil is saturated due to excessive rain, flooding, high water table, or other conditions, soil cohesion and shear strength may be reduced, resulting in a loss of root anchorage. Site preparation work can change soil hydrology and affect moisture levels.
- **Soil erosion.** Loss of soil from around tree roots due to wind or water flow can reduce root contact with the soil and reduce tree stability.

Tree Species Failure Profiles

Recurring patterns of tree failure are observed for many tree species and locations. Species failure profiles identify commonly observed failure points. Tree risk assessors should consider species failure patterns when performing tree risk assessments. Knowing the most common ways in which a species fails can help the assessor determine the relevance of certain conditions and when a higher level of assessment may be needed. For example:

- Failure of coast live oak (*Quercus agrifolia*) is often associated with internal decay. Because of this, the assessor should pay particular attention to signs and symptoms of decay when inspecting that species.

E. Thomas Smiley

Figure 6.30 When there is fill soil over the root system, the original roots may decline or experience reduced growth, and adventitious roots may develop closer to the soil surface. Both suppressed roots and adventitious roots are visible in this photograph.

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E. Thomas Smiley

Figure 6.31 Tree root growth may be suppressed underneath pavement.

- Many failures of blue gum eucalyptus (*Eucalyptus globulus*) are associated with strong winds. When assessing that species, the assessor should carefully consider the tree's exposure to prevailing wind direction, wind direction during storms, and the occupancy of mobile targets in the target zone during wind events.

Species profiles have been developed locally (e.g., Western Tree Failure Database) and they have been developed from species-specific studies. When considering species profiles, the assessor should be aware that while a profile may be helpful, it is not a substitute for inspecting the whole tree and site. Just because a species has a reputation for a *low* likelihood of failure does not mean that a particular tree of that species is unlikely to fail.

Visual Indicators of Root/Soil Defects That May Indicate an Increased Likelihood of Failure

- Dead or missing roots
- Fungal fruiting structures
- Lack of root flare
- Stem-girdling roots
- Dead or loose bark
- Wounded roots
- Root cuts
- Soil mounding or cracking
- Crown dieback or decline
- Restricted root space
- Soil erosion
- Excessive soil moisture
- Adventitious roots
- Termite nests/mounds at tree base
- Gap between the soil and the trunk/roots

Visual Indicators of Response Growth in the Root System

- Wide root flare
- Fused buttress roots
- Large adventitious roots

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Summary

In a basic risk assessment (Module 2) the tree risk assessor performs a ground-based, visual assessment of a tree and its surrounding site, and synthesizes the information collected. The assessment includes inspecting the crown, branches, trunk, root collar, visible roots, and site conditions.

Categorizing the likelihood of failure of one or more branches, the stem, the roots, or the soil holding the roots is a key part of risk assessment. There are two elements to consider when determining likelihood of failure: structural defects and conditions that may reduce or increase a tree's load-bearing capacity, and the loads that the tree is likely to experience within the stated time frame. Trees fail when the load(s) they experience exceed their load-bearing capacity.

Some structural defects or conditions are more likely to lead to failure than others. Individual defects or conditions may not by themselves indicate a serious structural problem, but when more than one defect or condition is present in a tree, their combined effect on likelihood of failure should be considered.

Key Concepts

1. Defects are imperfections, weaknesses, or lack of something necessary. In trees, defects include injuries, growth patterns, decay, branch arrangement and attachment configurations, and other conditions that may increase the likelihood of failure.
2. A tree assessment considers defects, response growth, weather, soil, and other conditions that may increase or decrease the likelihood of failure.
3. The likelihood of failure associated with decay depends on the tree species, the extent and location of the decay, the presence of other defects, the expected loads, and the amount of response growth.
4. Fresh cracks associated with decay, horizontal (transverse) cracks, and cracks that penetrate all the way through a branch or stem can greatly increase the likelihood of failure.
5. Because tree growth and branching characteristics can affect how loads are distributed, problems with other defects can become more significant when tree architectural abnormalities are present.

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Data Analysis and Risk Categorization

Module 7

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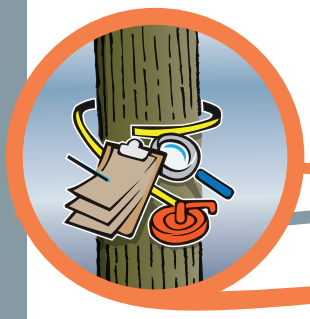

Data Analysis and Risk Categorization

Module 7

Learning Objectives

- Discuss the process of categorizing likelihood of failure, likelihood of impact, and consequences of failure.
- Describe the factors to consider when determining the likelihood of a failed part impacting the target and assigning one of the four likelihood of impact categories.
- Explain how the Likelihood Matrix (Matrix 1) is used to determine the likelihood of failure and impact.
- Explain how the Risk Matrix (Matrix 2) is used to rate the level of risk based on likelihood and consequence ratings.
- Explain how to determine the overall risk rating.
- Explain how clients' perception of risk and their risk tolerance affect the thresholds for action to mitigate risk.

Key Terms

acceptable risk
consequences of failure
Likelihood matrix (Matrix 1)
likelihood of failure
likelihood of failure and impact
likelihood of impact
occupancy rate
overall tree risk rating
risk categorization
risk evaluation
Risk matrix (Matrix 2)
risk tolerance
subjectivity
tree risk rating
time frame
uncertainty

Likelihood of Failure	Likelihood of Impact	Likelihood of Failure and Impact	Consequences of Failure	Risk Ratings
imminent	*high*	*very likely*	*severe*	*extreme*
probable	*medium*	*likely*	*significant*	*high*
possible	*low*	*somewhat likely*	*minor*	*moderate*
improbable	*very low*	*unlikely*	*negligible*	*low*

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Introduction

By this point in the process, the **time frame** for likelihood of failure and impact has been established, targets have been identified and the tree has been examined. The task now is to categorize the **likelihood of failure**, the **likelihood of impact**, and the severity of potential **consequences of failure** if failure and impact occurs. Once that data is analyzed, the risk can be categorized and a **tree risk rating** can be determined.

The Risk Categorization Process

To categorize risk, the tree risk assessor combines the likelihood of failure, the likelihood of impact, and the consequences of failure using two matrices. This is done for all failure types and targets being considered within the specified time frame. The process starts with the **Likelihood Matrix (Matrix 1)** which combines the likelihood of failure and the likelihood of impacting the target to determine likelihood of failure and impact. The likelihood of failure and impact is then combined with the consequences of failure using the **Risk Matrix (Matrix 2)** to determine the risk rating.

1. Categorize the likelihood of failure, the likelihood of impact, and the consequences of failure.
2. Apply the Likelihood Matrix (Matrix 1) to combine the likelihood of failure and the likelihood of impact to categorize the likelihood of failure and impact.
3. Apply the Risk Matrix (Matrix 2) to combine the likelihood of failure and impact (the result of Matrix 1) with the consequences of failure to determine the level of risk.

Review of Likelihood of Failure and Likelihood of Impact

Likelihood of Failure

The likelihood of failure is the chance of a tree failing within the specified time frame. Likelihood of failure is categorized based on the presence of defects and conditions that affect tree failure, response growth, species failure profiles, tree health, site conditions, and anticipated loads, including weather.

Definitions of Some Key Terms

Several key terms are required for understanding the categorization of tree risk. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

acceptable risk—the degree of risk that is within the tolerance or threshold of the tree risk manager or controlling authority.

consequences of failure—personal injury, property damage, or disruption of activities due to the failure of a tree. Categories are *severe*, *significant*, *minor*, and *negligible*.

likelihood of failure—the chance of a tree failure occurring within the specified time frame. Categories are *imminent*, *probable*, *possible*, and *improbable*.

likelihood of failure and impact—the chance of a tree failure occurring within the time frame and impacting a target. Categories are *very likely*, *likely*, *somewhat likely*, and *unlikely*.

likelihood of impact—the chance that if the tree fails during the specified time frame, it will impact a target. Categories are *high*, *medium*, *low*, and *very low*.

occupancy rate—the amount of time a target is within a target zone within the time frame specified for the risk assessment. Categories are *constant*, *frequent*, *occasional*, and *rare*.

time frame—the period for which an assessment is defined.

tree risk rating—the combination of likelihood of failure and impact with consequences of failure. Categories are *extreme*, *high*, *moderate*, and *low*.

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Categorizing the Likelihood of Failure

The likelihood of failure is categorized as follows:

- ***Imminent*** indicates that failure has begun or will occur soon in normal weather or with minimal additional loading.
- ***Probable*** indicates that failure may occur in normal weather and is expected to occur in severe weather within the specified time frame.
- ***Possible*** indicates that failure is not likely in normal weather but may occur in severe weather within the specified time frame.
- ***Improbable*** indicates that failure is not likely in normal or severe weather within the specified time frame.

Likelihood of Impacting the Target

The second factor to be considered is the likelihood of the failed tree impacting the target within the specified time frame. To categorize this likelihood, estimate the **occupancy rate** of targets within the target zone, the likely direction of fall (in relation to the target location within the target zone), and any factors that could protect the target from impact by the falling tree. For example, a static target may be directly underneath a broken branch but protected from impact by lower branches or built structures. In this example, the occupancy rate is *constant*, but the likelihood of impact might be *very low* because of the protection factors.

Categorizing the Likelihood of Impact

The likelihood of impacting a target within the specified time frame is categorized as follows:

- ***High*** indicates the failed tree is likely to impact the target. This only applies when there is *constant* occupancy within the target zone, no protection, and the direction of fall is toward the target.
- ***Medium*** indicates the failed tree could impact the target but is not expected to do so. This could apply, for example, when mobile targets are frequently within the target zone and the direction of fall is toward the target, when the direction of fall may or may not be toward a static target within the target zone, or when a static target has *constant* occupancy and may be protected from the falling tree.
- ***Low*** indicates there is a slight chance that if the tree were to fail it will impact the target. This could apply, for example, when mobile targets are occasionally in the target zone, when the expected direction of fall is not toward the target, or when a *constant* target is protected from the falling tree.
- ***Very low*** indicates the chance of the failed tree impacting the specified target is remote. Likelihood of impact could be *very low* if the occupancy rate is *rare*, the tree is likely to fall in the opposite direction of the target, the occupancy rate is *occasional* and the tree may or may not fall toward the target, the occupancy rate is *frequent* and the tree is likely to fall in a different direction, or the occupancy rate is *constant* and the tree would fall in a different direction or the target is well protected.

Categorizing Likelihood of a Tree Failing and Impacting a Target

After determining the likelihood of failure and the likelihood of impacting a target, the combined **likelihood of a failure and impact** can be categorized using the Likelihood Matrix (Matrix 1). The resulting terms (*unlikely*, *somewhat likely*, *likely*, and *very likely*) are defined by their use within the matrix and are used to represent this combination of occurrences in the Risk Matrix, which will be introduced later.

Figure 7.1 is an example of determining the likelihood of a failure impacting a target. A tree with a large, dead branch is growing next to a house. The dead branch is on the side of the tree away from the house and assigned a *probable* likelihood of failure within a one-year time frame.

Because the house is a static target, its occupancy rate in the target zone is *constant*. However, the likelihood of impact of the branch falling from the

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Matrix 1 The Likelihood Matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Table 7.1 Example of using the likelihood matrix with Figure 7.1 to combine the likelihood of failure and the likelihood of impact to categorize the likelihood of failure and impact.

Target (in **bold**)	Occupancy Rate (in **bold**)	Likelihood of Impact (in **bold**)	Likelihood of Failure (in **bold**)	Likelihood of Failure & Impact (in **bold**)
People near the tree	***Rare***: walking to or from car and house, mowing lawn, etc.	***Very low***: based on occupancy rate	Large dead branch categorized as ***Probable*** failure within the next year	In the likelihood matrix, the combination of *Probable* and *Very low* makes the likelihood ***Unlikely***
Car parked under dead branch	***Frequent***: typically present all night and part of the day	***Medium***: based on occupancy rate and direction of fall	Likelihood of failure of the branch (***Probable***) does not change, only the target changes	In the likelihood matrix, the combination of *Probable* and *Medium* makes the likelihood ***Somewhat likely***
House	***Constant***: always present and unprotected	***Very low***: because it would be unusual for the branch to land on the opposite side of tree	Likelihood of failure of the branch (***Probable***) does not change, only the target changes	In the likelihood matrix, the combination of *Probable* and *Very low* makes the likelihood ***Unlikely***

Casey Jones

Figure 7.1 Tree risk is a combination of the likelihood of failure and impact with the severity of the consequences. In deriving a risk rating, consider the targets, the likelihood of failure, the likelihood of the failed tree (or tree part) impacting a target, and the consequences of the failure and impact.

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opposite side of the tree through the rest of the tree to the house is *very low*. Combining likelihood of failure (*probable*) and likelihood of impact (*very low*) using the Likelihood Matrix results in a rating of *unlikely*.

Alternatively, if there is a car parked directly under the branch and there are no lower branches that would stop the fall of the branch, the likelihood of impact is greater. If a car is parked under the tree for part of most days and every night, and the driver is present for a few minutes each day as they walk between the house and the car, the occupancy rate for a person in the target zone is assessed as *rare* and the occupancy rate for the car is *frequent*.

With no factors that would affect the fall of the branch on this side of the tree, the likelihood of impact on the car is *medium*. Using the Likelihood Matrix (Matrix 1) to combine the *medium* likelihood of impact with the *probable* likelihood of failure of the branch, the likelihood of failure and impact for the car is *somewhat likely*.

The *rare* occupancy rate for a person results in a *very low* likelihood of impact. When combined with a *probable* likelihood of failure, this results in the likelihood of a failure and impact as *unlikely*. As illustrated in this example, it is common to have multiple targets with different values and occupancy rates.

Review of Consequences of Failure

The consequences of a tree failing and impacting a target are based on the degree of injury, damage, or disruption that could be caused. The amount of damage depends on the target's susceptibility to harm, size of the tree or tree part, how far it will fall before impacting the target, and the presence of factors that may protect the target from harm.

Categorizing Consequences of Failure

Consequences of failure and impact can be categorized as follows:

- ***Severe*** consequences are those that could involve serious personal injury or death, high-value damage to property, or major disruption of important activities.
- ***Significant*** consequences are those that involve significant personal injury, substantial damage to property, or considerable disruption of activities.
- ***Minor*** consequences are those that involve minor personal injury, low- to moderate-value damage to property, or some disruption of activities.
- ***Negligible*** consequences are those that involve no personal injury, low-value damage to property that can be replaced or repaired, or short-term disruption of activities.

Rating Risk

The Risk Matrix (Matrix 2) is used to combine the likelihood of failure and impact rating with the consequences of failure to determine a risk rating. The matrix was designed specifically for the analysis of risk posed by tree failures.

Categorizing Risk Ratings

In the Risk Matrix, four terms are used to categorize levels of risk: *extreme*, *high*, *moderate*, and *low*. They are defined by their location within the Risk Matrix—that is, at the intersection of the likelihood of a tree failure and impact, and the severity of the consequences. The risk ratings are used to communicate the level of risk to the tree risk manager.

Extreme—*Extreme*-risk trees are those for which the highest level of each factor of risk assessment is selected: failure is *imminent*, there is a *high* likelihood of impacting the target, and the expected consequences of failure are *severe* (Figure 7.2). The tree risk assessor should recommend that mitigation measures be taken as soon as possible. In some cases, this may mean that the tree risk manager needs to restrict access to the target zone area to avoid injury to people.

High—*High*-risk trees are those for which consequences are *significant* and likelihood is *very likely* or *likely*, or consequences are *severe* and likelihood is *likely* (Figure 7.3).

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Matrix 2 Risk matrix showing the level of risk as the combination of likelihood of a tree failure impacting a specified target, and the severity of the associated consequences

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Table 7.2 Example of using the risk matrix to combine the likelihood of failure and impact with the consequences of failure and impact. (The Likelihood of Failure and Impact column is carried over from Table 7.1.)

Target (in **bold**)	Likelihood of Failure & Impact from the Likelihood Matrix (in **bold**)	Consequences of Failure & Impact(in **bold**)	Tree Risk Rating (in **bold**)
People near the tree	In the likelihood matrix, the combination of *Probable* and *Very low* makes the likelihood ***Unlikely***	***Severe***: a person struck by the large branch could be killed	In the risk matrix, the combination of *Unlikely* and *Severe* makes the risk rating ***Low***
Car parked under dead branch	In the likelihood matrix, the combination of *Probable* and *Medium* makes the likelihood ***Somewhat likely***	***Significant***: a car struck by the large branch could be badly damaged	In the risk matrix, the combination of *Somewhat likely* and *Significant* makes the risk rating ***Moderate***
House	In the likelihood matrix, the combination of *Probable* and *Very low* makes the likelihood ***Unlikely***	***Minor***: a house struck by the large branch (e.g., if it shattered on impact) would not sustain much damage	In the risk matrix, the combination of *Unlikely* and *Minor* makes the risk rating ***Low***

Casey Jones

Figure 7.1 (repeated) Example of using the Risk Matrix to combine the likelihood of failure and impact with the consequences of failure and impact.

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Kevin Kenny

Figure 7.2 *Extreme* risk. The tree risk assessor discovered root failure due to advanced root decay on this tree alongside a busy street in New York City. It has an *imminent* likelihood of failure, *high* likelihood of impacting the target, and *severe* consequences of failure. *Extreme* risk occurs only when all three factors are at their highest level. The assessor contacted the tree risk manager, who immediately installed the caution tape, which will remain until the tree can be removed.

E. Thomas Smiley

Figure 7.3 *High* risk. This tree has significant decay in the lower trunk, and the likelihood of failure is *probable* within a three-year time frame. The likelihood of impacting the house is *high* because of the lean, making the likelihood of failure and impact *likely*. The consequences of failure are *significant*. This combination results in *high* risk.

E. Thomas Smiley

Figure 7.4 *Moderate* risk. The likelihood of failure for one of the codominant stems is *probable* within a three-year time frame, and the likelihood of impacting a person below is *medium* due to the *frequent* use of the site. The combined likelihood of failure and impact is *somewhat likely*. The consequences of failure would be *severe* for people under the tree, resulting in a *moderate* risk rating.

Luana Vargas

Figure 7.5 *Low* risk. Likelihood of failure of the foreground tree is *possible* within a three-year time frame. With a likelihood of impact of *medium*, the likelihood of failure and impact is *unlikely*. Consequences of failure are *severe*, but when combined with *unlikely* failure and impact, the risk is *low.*

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Moderate—*Moderate*-risk trees are those for which consequences are *minor* and likelihood is *very likely* or *likely*; or likelihood is *somewhat likely* and consequences are *significant* or *severe* (Figure 7.4).

Low—*Low*-risk trees are those for which the lowest level of any factor of risk assessment is selected: whenever consequences are *negligible* or likelihood of failure and impact is *unlikely* (Figure 7.5). *Low* risk also applies when consequences are *minor* and likelihood of failure and impact is *somewhat likely*.

Multiple Failure Types and Targets

Many trees can fail in different ways and may have multiple targets. For example, a tree with extensive root decay might also have several dead branches; the whole tree could fail from root decay, or individual dead branches could fail. Similarly, the whole tree might fall on a house, while the dead branches might fall only on a driveway. When assessing a tree, it is appropriate to assess the combination of each failure type and target as an independent event. The assessor will report the risk rating for the combinations of concern, recommend mitigation options, and estimate residual risks. The assessment report should state what specific risk each rating applies to.

It is also possible for the same failure type and target combination to result in different outcomes. For example, a tree could fall onto a busy highway and strike a vehicle, or it could fall into the street and disrupt traffic. Another example is a tree failure onto power lines. A tree falling on power lines could disrupt power to customers, electrocute a nearby pedestrian, or potentially cause a wildfire. All three of these outcomes may have different likelihood of impact and consequences ratings. It may be appropriate to assess the risk of each of the outcomes separately because both the likelihood of impact and the consequences could differ.

Overall Tree Risk Rating

The **overall tree risk rating** is the highest risk rating determined for a tree. The tree risk assessor identifies—among all the assessed combinations of failure type and target—the combination presenting the highest risk and reports it as the overall tree risk rating. For example, a whole-tree failure impacting a target may be *unlikely*, but it could have *significant* consequences if it occurs; using Matrix 2, the risk rating is *low*. At the same time, the likelihood of failure and impact of a dead branch may be *very likely*, but with *minor* consequences; the risk rating is *moderate*. The overall risk rating would be reported as *moderate*, the higher of the two ratings.

The overall tree risk rating is often presented as the single risk level for the tree, especially when dealing with populations of trees and limited visual assessments. The overall risk rating can be helpful when prioritizing risk mitigation. If actions are taken to mitigate the highest risk, residual risk associated with that tree may still exist. The overall tree risk rating for that tree may or may not change based upon the remaining risk factors.

Variability Among Assessors' Ratings

One measure of the reliability of a tree risk assessment methodology is the degree of consistency of ratings among trained and knowledgeable users. Tree risk assessors considering the same trees should usually arrive at similar ratings for likelihood of failure, likelihood of impact, and severity of consequences. However, complete consistency among assessors may not be achieved because of inherent uncertainty and subjectivity.

Uncertainty and Subjectivity

Conditions such as wind loads, loss in load-bearing capacity due to decay or defects, specific targets, and target zone occupancy are impossible to know precisely. Some degree of **uncertainty** is unavoidable and therefore, assessing tree risk is inherently imprecise.

The categorization of factors of tree risk assessment—likelihood of failure, likelihood of impact, and severity of consequences—can be influenced by the assessor's education, experience, and personal **risk tolerance**. This **subjectivity** is inherent but can

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be managed by defining and calibrating the ratings categories and training the users. This publication provides guidance and many examples to aid assessors in calibrating their ratings.

Reasonableness Check

The majority of trees in an urban population will typically be categorized as *low* risk. Smaller proportions will be categorized as *moderate* risk and *high* risk. Under normal circumstances, *extreme*-risk trees are rarely encountered.

If an assessor categorizes more than a few *high*- or *extreme*-risk trees on a regular basis, they should review the categorization guidelines for occupancy rate, likelihood of failure, likelihood of impact, and severity of consequences.

It is also helpful to calibrate ratings with other experienced professionals. Opportunities to compare ratings among risk assessors are more readily available to assessors who frequently work with colleagues, but all assessors should be concerned about consistency.

Assessors should ensure that their categorizations are well calibrated with the guidelines in this publication. Each factor (likelihood of failure, likelihood of impact, and consequences of failure) must be rated independently of the others. For example, an assessor must not consider the likelihood of impact when rating consequences of a failure.

Intentionally overrating risk to achieve a tree risk manager's objective is unethical and harms the profession.

Risk Perception and Acceptable Risk

It is impossible to maintain trees completely free of risk; some level of risk must be accepted to experience the benefits that trees provide. How people perceive risk and their need for personal safety is inherently subjective; therefore, risk tolerance and action thresholds vary among tree risk managers. What is acceptable to one person may be unacceptable to another.

Acceptable risk is the degree of risk that is within the tolerance or threshold of the tree risk manager or controlling authority. In some countries, a controlling authority (e.g., a government agency) defines thresholds of risk. In addition, municipalities, utilities, and property managers may have a risk management plan that defines the level of acceptable risk.

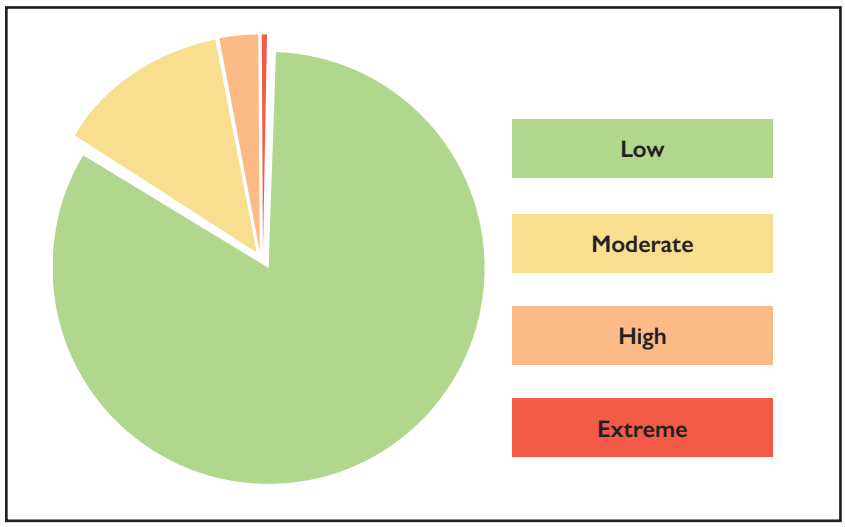

Figure 7.6 Conceptual tree risk rating distribution for an urban tree population.

Safety may not be the only criterion used by the tree risk manager to establish acceptable levels of risk; budget, a tree's historical or environmental significance, aesthetics, and other factors also may influence the decision-making process.

The tree risk assessor should choose words carefully to avoid unintended meanings. The tree risk assessor is cautioned against declaring a tree to be "safe" or suggesting that trees can be made "safe." Such declarations or suggestions could have serious implications if a case ends up in court. Trees are living organisms that

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sometimes fail unexpectedly despite reasonable efforts to maintain them.

Risk Evaluation

Risk evaluation is the process of comparing the assessed risk against given risk criteria to determine the significance of the risk. This is usually done by the tree risk manager, sometimes in consultation with the risk assessor. The tree risk assessor presents the level of risk determined along with recommended mitigation actions or options, and their associated residual risks. Mitigation and residual risk are presented in Module 8. The tree risk manager must then decide on what actions, if any, to take.

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Figure 7.7 How people perceive risk and their need for personal safety is inherently subjective; therefore, risk tolerance and action thresholds vary among tree risk managers.

Steps in Developing a Tree Risk Rating

1. Develop a scope of work to define the level and details of the risk assessment, the time frame, and other necessary information.
2. Identify targets, as specified (limited visual assessment) or informed by the tree risk manager, or as observed (basic and advanced assessments). Categorize the occupancy rate of targets.

   (*Constant* / *Frequent* / *Occasional* / *Rare*)
3. Identify potential failure types—the manner in which a tree or tree part could fail.
4. Assess and categorize the likelihood of failure for each failure type within the specified time frame.

   (*Imminent* / *Probable* / *Possible* / *Improbable*)
5. Assess and categorize the likelihood of the tree impacting the target.

   (*High* / *Medium* / *Low* / *Very low*)
6. For each failure type/target combination, categorize the likelihood of failure and impact (Matrix 1).

   (*Very likely* / *Likely* / *Somewhat likely* / *Unlikely*)
7. For each failure type/target, assess and categorize consequences.

   (*Severe* / *Significant* / *Minor* / *Negligible*)
8. For each failure type/target, categorize the risk (Matrix 2).

   (*Extreme* / *High* / *Moderate* / *Low*)
9. The tree's overall tree risk rating is the highest risk rating determined.

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CASE STUDY

Using the Matrices

Assignment: The homeowner contracted a Level 2 risk assessment of a native valley oak (*Quercus lobata*) that overhangs a neighboring property.

Time Frame: Two years.

Targets and Site: Targets include people in the back garden (*occasional* occupancy, no protection), and the house (*constant* occupancy). The tree is partially protected from the wind and there is no irrigation.

Tree Conditions: The crown is unbalanced, and there are several dead branches up to 6 in (15 cm) diameter that overhang the garden. There is a cavity visible at 10 ft (3 m) above grade and a fungal conk below it, indicating extensive heartwood decay.

Analysis: The likelihood of branch failure was categorized as *probable* and the likelihood of trunk failure was categorized as *possible* within a two-year time frame. The likelihood of impact for branch failure was categorized for people as *low*, and for the house as *medium*. The likelihood of branch failure and house impact is *somewhat likely*. The likelihood of impact for a trunk failure was categorized for people as *low* and for the house as *high*.

Matrix 1 was used to categorize the combined likelihood of failure and impact for each target/failure type combination.

Tree Part Branches, Trunk, Root Collar, Roots, or Soil	Failure Type Dead, Hanging, Decay, Crack, etc.	Target Description or Number	Likelihood of Failure				Likelihood of Impact				Failure and Impact from Matrix 1				Consequences				Risk Rating from Matrix 2
			Improbable	Possible	Probable	Imminent	Very low	Low	Medium	High	Unlikely	Somewhat	Likely	Very likely	Negligible	Minor	Significant	Severe	
Branches	Dead	People			x			x			x							x	low
		House			x				x			x				x			low
Trunk	Decay	People		x				x			x							x	low
		House		x						x		x					x		mod

Overall tree risk rating: ☐ Low ☒ Moderate ☐ High ☐ Extreme

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Consequences to people from either a branch or trunk failure and impact were categorized as *severe*. Consequences to the house from a branch failure and impact was categorized as *minor*, and for trunk failure and impact as *significant*.

Matrix 2 was used to categorize the risk ratings: for dead branches impacting people the risk rating was *low*; for dead branches impacting the house the risk rating was *low*; for trunk failure impacting people the risk rating was *low*; for trunk failure impacting the house the risk rating was *moderate*.

The overall tree risk rating for the tree was *moderate* because the highest risk rating was *moderate*.

Mitigation Options: Consider advanced assessment to determine the size and extent of the decay.

1. Remove the tree to eliminate the risk of whole-tree failure.
2. Prune to remove the dead branches. Even though the risk from branch failure is low, it can be reduced further by removing the dead branches. The residual risk after pruning would remain *moderate* because of the trunk decay.
3. Retain and reassess. There will be no change to the likelihood of failure, impact, or consequences. The residual risk would remain *moderate*.

Reporting: A written report was submitted to the tree owner/tree risk manager.

The tree owner decided to prune the dead branches over the house as well as some live branches over the house.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

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Summary

Assessment of the tree and site are used to categorize the likelihood of failure, the likelihood of impacting a target, and the consequences of the failure and impact within the specified time frame. This information is used to analyze the risk of each failure type/target combination using two matrices. The risk of each of these failure type/target combinations can then be used to identify the overall tree risk rating.

Once determined, the risk rating(s) is presented to the tree risk manager along with mitigation options and information on residual risk. The tree risk manager then analyzes the risk information and determines which action, if any, to take.

Key Concepts

1. The likelihood of tree failure, the likelihood of the failed tree impacting a target within the specified time frame, and likely consequences of the failure and impact are determined while assessing the tree.
2. The Likelihood Matrix (Matrix 1) is used to combine the likelihood of failure and the likelihood of impact.
3. Consequences of tree failure and impact are categorized based on the value of the target and harm that may be done to it. The Risk Matrix (Matrix 2) is used to combine the likelihood of failure and impact with the consequences of the failure and impact and determine a risk rating for each failure type/target combination.
4. The overall tree risk rating is based on the highest level of risk determined for the tree, considering each target/failure type assessed.
5. The tree risk manager is responsible for determining if the level of risk is acceptable and the mitigation action, if any, to take.
6. For *extreme*-risk trees, the tree risk assessor should notify the tree risk manager as soon as possible so they can take action to avoid injury.

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Mitigation

Module 8

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Mitigation

Module 8

Learning Objectives

- Discuss tree risk mitigation options, including tree-based and target-based options.
- Prescribe mitigation options for identified risks.
- Describe how the mitigation options will reduce the identified risk issues.
- Discuss the options for improving tree health or reducing growth rates for long-term risk mitigation.
- Assess the expected residual risk following mitigation actions.
- Explain the considerations in recommending options to a tree risk manager.

Key Terms

brace rod (rigid brace)
cable (flexible brace)
guy
lightning protection system
mitigation
mitigation options
prop
pruning
residual risk
retain and reassess
site modification
structural support system
target-based mitigation
tree-based mitigation
tree growth regulator
veteran tree
wildlife habitat

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Introduction

Mitigation is the process of reducing risk. Actions to mitigate risk can be tree based, most frequently to reduce the likelihood of failure, or they can be target based, to reduce the likelihood of impact or the consequences. For both approaches, the recommended actions should be practical and effective. For each **mitigation option**, an assessor should also estimate the risk that would remain after the work is completed—the **residual risk**.

Mitigation actions are typically presented as a set of options to the risk manager, and it is ultimately the tree risk manager's responsibility to choose which option to implement. Mitigation recommendations should be reasonable and proportionate. This means that mitigation measures are in balance with the risk and benefits of the tree. Taking actions that are disproportionate to the risk can remove trees unnecessarily and eliminate the benefits the tree provides, as well as waste money and resources.

Definitions of Some Key Terms

Several key terms are required for understanding tree risk mitigation. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary of Terms.

mitigation—the process for reducing risk.

residual risk—risk remaining after mitigation.

target-based mitigation—action focused on the target; risk mitigation actions are aimed at reducing the likelihood of impact or the consequences but do not change the likelihood of failure.

tree-based mitigation—action performed on the tree; risk mitigation actions are typically aimed at reducing the likelihood of tree failure but may also reduce the likelihood of impact or consequences.

When recommending mitigation actions, tree risk assessors should avoid using definitive words that exceed their role as risk assessor. For example, tree risk assessors should avoid stating that a tree *must* be removed because it implies that the tree risk assessor has moved into the role of tree risk manager. Instead, the tree risk assessor should state they *recommend* tree removal, which still leaves the decision to the tree risk manager.

Target-Based Mitigation

Movable targets within the target zone can sometimes be temporarily or permanently relocated. An assessor should consider whether mobile targets, such as pedestrians or vehicular traffic, can be rerouted or restricted from entering the target zone. These are often the solutions that will have the lowest impact on the tree and are often preferred if tree preservation is a primary management goal.

Avery Lewis

Figure 8.1 Mitigation actions are typically presented as a set of options to the tree owner or risk manager; it is ultimately the risk manager's responsibility to choose which option to implement. Both target-based and tree-based options should be considered.

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Casey Jones

Figure 8.2 With movable targets, one option for risk mitigation is to relocate the target outside of the target zone. However, people may move the target back into the target zone, unaware of the risk. Target-based mitigation actions have the lowest impact on the tree and are often preferred if tree preservation is a primary management goal.

Sometimes, **target-based mitigation** options are employed as temporary measures to immediately reduce risk until other measures can be taken. Other times, the changes are permanent. Target management may be limited by costs, public sentiments, and/or the willingness of tree risk managers to implement the actions.

For trees with *extreme* risk, the assessor should notify the tree risk manager as soon as possible so that the manager can consider restricting access as quickly as possible. Restricting access to the target zone should also be considered for *high*-risk trees. In addition, relocating movable targets or reducing the occupancy rate of mobile targets may be a viable option at any level of risk.

Target-Based Actions

- Move the target out of the target zone
- Restrict access to the target zone
- Reroute traffic around the target zone
- Target protection

Tree-Based Mitigation

Tree-based mitigation includes arboricultural practices such as tree removal, pruning, and installation of support systems.

Tree-Based Actions

- Prune to remove or reduce load on parts likely to fail
- Cable, brace, guy, or prop to provide support for weak areas
- Install lightning protection system, if warranted
- Remove the tree (and replace if appropriate)
- Modify the site to improve conditions for the tree
- Use tree growth regulators to extend the effective period of mitigation

Pruning

Pruning can be done for many reasons, including mitigating risk. Dead, dying, and weakly attached branches can be pruned in accordance with the applicable national pruning standards or ISA's BMP—*Pruning*. Wind loads can be reduced with reduction pruning. Very often, topping is not acceptable because of the potential for long-term problems with weak sprouts and the entry of wood decay fungi. It is also not appropriate to prune branches excessively with the intent of reducing drag.

Crown raising removes lower branches that could be interfering with structures, pedestrians, vehicle traffic, signs, or views. Excessive pruning, however, can change how a tree moves and grows; it can also adversely affect tree health. The long-term effects of pruning on the likelihood of failure have not been well studied.

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As some trees become old, the crown structure may change with loss of branches, a process called retrenchment or natural crown reduction. In this process, tree height and crown width decrease, which reduces the potential wind loads and may increase stability. Eventually, however, even tall stumps without branches will fail when the roots decay. For this reason, declining trees that are retained near significant targets should be monitored and considered for removal or further mitigation before risk exceeds the risk manager's risk tolerance. An example of this is trees that are retained for wildlife habitat.

Dwayne Neustaeter

Figure 8.3 Pruning is commonly used to mitigate risk associated with defective branches, including branches that are dead, dying, or weakly attached.

Pruning to mitigate risk needs to be considered in the context of the overall health and vigor of the tree, and whether the tree can tolerate the proposed pruning. In addition to a tree's health and vigor, the species, age, and growing conditions can affect tolerance of the type and severity of pruning. Consider the ability of the tree to:

- Compartmentalize and limit decay from the pruning cuts
- Recover from the loss of leaf area
- Sprout from latent buds and develop new leaf area

E. Thomas Smiley

Figure 8.4 Branch reduction cuts can be made to reduce the length and weight of branches, thereby reducing the load and likelihood of branch or whole tree failure.

Installing Structural Support Systems

Structural support systems can be installed to limit movement of certain tree parts in accordance with ISA's BMP—*Tree Support Systems*. Various types of hardware are used, depending on the goals. Examples include:

- **Cables** (**flexible braces**) installed in the upper crown to limit the movement of weak unions or codominant stems; cables may be made of steel or synthetic fiber such as polypropylene
- **Brace rods** (**rigid braces**) installed close to or through weak unions, or through split sections
- **Guys** installed to improve anchorage and stabilize lean
- **Props** installed to support some leaning trees and low branches from below

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E. Thomas Smiley
E. Thomas Smiley
E. Thomas Smiley
Brian Kane

Figure 8.5 Structural support systems can be installed to limit movement of certain tree parts. Hardware can include: (a) cables, (b) brace rods, (c) guys, or (d) props.

When recommending the installation of support systems, consider not only the reinforcement of specific tree parts but also the support system's potential effect on the whole tree. The relevant standards and ISA's BMP—*Tree Support Systems* should be consulted when adopting this option.

Installing Lightning Protection Systems

In locations prone to lightning, large trees, exposed trees, trees on elevated sites, and trees close to water may be struck. A tree that is struck by lightning may be minimally injured, or it may be killed, structurally damaged, or even blown apart—posing a risk to any potential targets. Large and/or significant trees that are likely to be struck, or susceptible trees in locations with *significant* and *severe* consequences, can be protected from lightning damage by installing a **lightning protection system**. These systems are designed to carry the charge of a lightning strike to ground to protect a tree from significant damage, so they are more of a preventive measure than a treatment. Installation of a lightning protection system

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in a tree can also minimize the risk of side flash to nearby structures. The relevant national standards and ISA's Best Management Practices—*Lightning Protection Systems* should be consulted when adopting this option.

Tree Removal

Tree removal may be an obvious choice in some situations, but in others it should be the last and least desirable option. Tree removal should be considered for *extreme*- and *high*-risk trees that are not suitable for retention, for example, as wildlife habitat or **veteran trees**, and in situations in which the target cannot be moved or restricted. Risk mitigation options must balance risk reduction against loss of environmental, social, and economic benefits. Rather than removing a tree, there are often other options available that can be used singly or in combination to reduce risk to an acceptable level.

E. Thomas Smiley

Figure 8.6 Installation of a lightning protection system may be a good mitigation option for large and/or significant trees that are likely to be struck, or for susceptible trees in locations with *significant* or *severe* consequences of failure.

E. Thomas Smiley

Figure 8.7 Tree removal may be an obvious choice in some situations, but in others it should be the last and least desirable option. Tree removal should be considered for *extreme*- and *high*-risk trees.

Modifying the Site to Enhance Mitigation

Site modification to improve conditions for the tree may improve tree health by allowing time for the tree's response growth to reduce the likelihood of failure. Modifying the site can also protect a tree from exposure to loads.

A common site modification to improve tree health is to improve soil conditions to encourage root growth. Increasing tree vigor through site modification can allow time for the tree's response growth to mitigate risk of failure due to various aboveground and belowground defects and conditions. Over time, development of new roots adds to tree stability, and development of new wood compensates for the loss in load-bearing capacity due to decay.

Additional site modifications to improve tree health may include:

- Applying mulch to improve soil conditions for root growth

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- Modifying irrigation systems to avoid wetting the trunks of species prone to root and root collar diseases, and to avoid saturating the soil
- Irrigating trees susceptible to drought, as needed
- Improving drainage in wet soil to reduce the likelihood of uprooting
- Removing fill soil placed against the trunk to reduce incidence of basal trunk disease and decay
- Removing turf around the base of a tree to enhance tree root growth
- Reducing soil compaction to allow greater root development
- Fertilizing to correct nutrient deficiencies
- Enlarging planter openings in paved areas to allow development of basal trunk flare and structural roots

Joe Bones

Figure 8.8 In some situations, the site conditions around a tree can be improved to enhance tree health. A common site-based option is to improve soil conditions to encourage root growth. Increasing tree vigor through site modification can allow time for the tree's response growth to mitigate the likelihood of failure. These measures may reduce risk in the long term and are sometimes recommended in conjunction with other mitigation strategies.

Site modifications to protect a tree can also be effective. Trees growing on a bank or slope may fail because of soil erosion, even if the root system is not damaged or decayed. Stabilizing banks or slopes to reduce erosion and slope failure can mitigate risk. In locations where trees are exposed to strong wind loads, modifications to buffer the wind may be utilized. This may involve planting additional trees or shrubs, or erecting structures on the windward side of the tree.

Site modification can be combined with options that restrict access to a site to reduce target occupancy. In situations of *extreme* or *high* risk, however, site improvement should not be the sole mitigation measure because it is unlikely that site improvement will decrease tree risk within the stated time frame. Some treatments to improve site conditions and reduce tree failure may take years or decades to be effective.

Using Tree Growth Regulators

Another possible enhancement to other mitigation actions is the application of tree growth regulators. **Tree growth regulators** (TGRs) alter growth hormones within a tree and are applied to reduce the elongation of stems. When TGRs are used in

Patrick Anderson

Figure 8.9 Tree growth regulators used in conjunction with pruning can extend the time before pruning is required again.

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conjunction with pruning, the effect(s) of pruning—such as reducing wind load or creating clearance from utility or other infrastructure—may be extended for a longer time. Because there is a time lag between the application of TGRs and their effect on the tree, their use may be most appropriate on *low*- and *moderate*-risk trees, or in combination with other mitigation measures. Use of TGRs to improve conditions should be considered a long-term mitigation measure. While they can be effective in reducing long-term risk, they will not immediately reduce risk. TGRs are not permitted in all regions.

Table 8.1 Tree-based mitigation options for specific tree defects where there are targets of concern. Mitigation actions may be used in combination. Also consider target-based mitigation options such as moving the target or restricting access within the target zone. Retain and reassess, though not a measure that immediately mitigates risk, is a recommendation that is sometimes an option when the tree risk is within the tree risk manager's tolerance.

Defect or Condition	Tree-based Mitigation Options	Description
Tree with significant decay in the trunk or structural roots	Pruning	If decay is limited, prune to reduce load on the crown. Retrenchment or crown reduction may be an option.
	Support system	Guy or prop if the tree is leaning excessively and decay is limited. Install anchors in solid wood.
	Removal	If decay is extensive and response growth is minimal.
Branch with crack or decay	Pruning	Prune to remove the branch or reduce the load on the branch.
	Support system	Install a cable system to limit branch movement. Install anchors in solid wood. If the branch is cracked, bracing should be combined with cabling.
	Removal	Whole tree removal is seldom recommended for branch or crown defects.
	Pruning	Prune to reduce branch length and weight.
Horizontal branch with poor taper and excessive end weight	Support system	If pruning will not adequately reduce the load on the branch, consider propping or cabling, in combination with pruning.
Recently exposed tree with poorly tapered trunk, high height:diameter ratio, and low live crown ratio	Pruning	Reduce crown height and/or branch spread.
	Support system	For high-value trees, consider installing a guy system as an option.
	Removal	If pruning, support systems, and target management are not practical or sufficient, remove the tree.
Leaning tree	Retain and reassess	If the top has returned to vertical (corrected lean), no treatment may be needed.
	Pruning	If the lean is moderate and not recent, prune to reduce load, branch length, or tree height.
	Support system	If practical, prop or guy the tree, in combination with pruning.
	Removal	For recent leans with mounded or cracked soil behind the lean, severe root cuts, or decay, remove the tree.
Codominant stems (two or more) with included bark and a "V"-shaped union	Pruning	Prune to reduce the length of one or more stems (subordination) or remove one or more of the stems.
	Support system	Install a cable system along with pruning.
	Removal	If pruning and/or a support system will not sufficiently reduce risk, remove the tree.
Numerous and/or weakly-attached regrowth (sprouts) from previous loss of top	Pruning	Prune to reduce the number of sprouts.
	Tree growth regulators (TGRs)	Apply as directed.
Tree with extensively decayed or severed buttress or structural roots near the trunk	Pruning	Prune to reduce load and size of crown (crown reduction).
	Support system	Guy or prop, if appropriate.
	Removal	If root loss is significant and the tree is exposed to strong winds, remove the tree.
Dead and/or hanging branches	Pruning	Prune to remove dead, broken, and/or hanging branches.

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Retention for Wildlife

Dead trees, as well as live trees with dead branches, decay, and cavities, provide habitat for many organisms. Dead trees or dead branches retained for **wildlife habitat** can be assessed for risk like any other tree. Selection of suitable wildlife habitat trees must consider the risk, as well as its value for wildlife. Removing a large portion of the trunk and branches may be appropriate to create or maintain wildlife habitat while managing risk. One management strategy is to maintain tree height less than the distance to the nearest target. Another strategy is to focus on retaining wildlife habitat trees that do not have valuable targets within the target zone. Incorporating fallen trees and cut branches into the landscape can be beneficial for wildlife but should only be considered where there are no greater risks associated, such as in fire-prone landscapes.

Mark Roberts

Figure 8.10 In some low-use locations, dead and decaying trees may be retained for wildlife habitat. When selecting trees for wildlife habitat, it is important to consider the short-term and long-term proximity of targets because their proximity can affect the level of risk.

It is important to consider nearby targets when selecting trees for wildlife habitat. Ideally, wildlife trees would be located in areas that have no significant targets within the target zone or that have only targets with a *rare* or *occasional* occupancy rate.

Very old and mature trees in natural settings may lose branches as they age and decline, a process sometimes called natural retrenchment. The trunk diameter may continue to grow while branches die and fail, reducing the overall height of the tree and increasing stability. Where tree risk is a concern, arborists can imitate this process by employing specific crown-reduction techniques. One management strategy for these trees is to maintain them at a height shorter than the distance to the nearest target. Some retrenched trees have remained stable for decades. Like wildlife trees, however, they should be monitored and should be considered for removal or mitigation if the risk exceeds allowable thresholds.

Multiple Mitigation Actions

Mitigation may involve more than one action. The tree risk rating based on the highest risk factor determines the overall tree risk, but typically there are other factors that also should be considered, which may require additional actions if the tree is to be retained. Once the highest risk factor has been mitigated, the tree risk rating shifts to the next highest risk level.

With some *extreme*-risk trees, mitigation may involve the immediate restriction of access within the target zone until other mitigation measures can be taken. Arborists should take appropriate precautions to maintain worker safety when working on these trees (e.g., using a crane or an aerial lift) because additional loads on the tree—from the weight of a climber or from lowering branches—may cause the tree to fail. With some *high*- or *extreme*-risk trees, removal is often the best or only option. For other trees, removal may not be necessary if other options (e.g., moving the target, pruning, or installing a support system) may reduce the risk to a level that is acceptable to the tree risk manager.

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Prioritizing Risk Mitigation

Prioritizing risk mitigation may be necessary when managing a population of trees, such as in municipal, utility, and institutional settings. The tree risk manager may prioritize mitigation beginning with trees that present the highest risk. If a tree risk assessor identifies an *extreme*-risk tree, the tree risk manager should mitigate the risk as soon as possible, which may include immediately restricting access to the target zone.

With a population of trees, prioritizing mitigation may also occur within each risk category (i.e., *extreme*, *high*, *moderate*, *low*). The tree risk manager should consider the budget; number, size, and location of trees; targets; and logistics of mitigation.

Trees with a *low* level of risk may benefit from mitigation or maintenance measures, but immediate action is not usually required. Tree risk assessors may recommend to **retain and reassess** these trees or to mitigate the risk. Although the risk is already in the lowest category, branches can be removed or reduced or other actions can be taken to reduce the likelihood of failure, likelihood of impact, or consequences. Even trees with an *improbable* likelihood of failure can fail within the time frame. With a single, privately owned tree, prioritizing mitigation is usually unnecessary because the tree owner (tree risk manager) decides what action to take and schedules the work.

"Retain and Reassess"

Retain and reassess is a recommendation that may be an option when the tree risk is within the tree risk manager's tolerance. Previously, some assessors used the phrase "retain and monitor," but there were questions about whether "monitor" implied more constancy than is practical. By specifying retain and reassess, an assessor emphasizes two important aspects of risk assessment: (1) the assessment is limited to what the assessor observes at the time of the assessment, and (2) conditions can (and do) change over time, which can alter the risk. Assessors should specify a time period for reassessment when recommending retain and reassess.

Residual Risk

Residual risk is the risk remaining after mitigation. Since mitigation may not eliminate all risk associated with a tree, there will be a residual risk. For example, an assessor determines the following risks associated with an individual tree:

- *High* risk from a dead branch directly over a street corner failing, striking a person, causing severe injury;
- *Moderate* risk from a second dead branch not directly over the corner failing and striking a person, causing severe injury;
- *Low* risk from failure of the whole tree striking several parked automobiles, causing significant damage.

If the dead branch directly over the street corner is removed, the residual risk is *moderate*, the next highest level. If both dead branches are removed, the residual risk would be *low*. The level of residual risk needs to be acceptable to the tree risk manager.

Tree risk managers may follow the principle of "as low as reasonably practicable" (ALARP), which has two components. The first component is that the residual risk does not exceed the tree risk manager's risk tolerance. The second is that further reducing the residual risk is unfeasible or the cost would exceed the benefit of additional mitigation.

In general, if the residual risk following a proposed mitigation exceeds the tree risk manager's risk tolerance, the proposed mitigation might not be the best choice. As previously noted, however, tree removal should not be recommended without consideration of the loss of tree benefits.

While the highest risk factor is often the focus of mitigation, the tree risk assessor may recommend mitigation for each condition assessed and estimate the residual risk following mitigation. The level of residual risk should be part of a basic tree risk assessment report so that the tree risk manager can make an informed decision about mitigation.

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E. Thomas Smiley

Figure 8.11 Restricting access to the target zone is a target-based mitigation action that preserves the tree. It is sometimes used in botanical gardens, arboreta, and similar sites.

Safety

With some *extreme*-risk trees, mitigation may involve the immediate restriction of use within the target zone before removing the tree. Safe tree removal may require using a crane or an aerial lift because additional loads on the tree from the weight of a climber or from lowering branches may cause the tree to fail.

Trees that pose a *high* or *extreme* risk to the public may pose an even higher risk for workers assigned to mitigate that risk. Before beginning work, tree workers should perform a pre-climb inspection. It also may be appropriate, in some cases, for risk assessment reports to communicate specific hazards for tree workers.

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CASE STUDY

Providing Mitigation Options

Assignment: Basic tree risk assessment (Level 2) of urban park trees.

Time Frame: Two years.

Targets and Site: Urban park; row of elms (*Ulmus* spp.) along a waterfront trail. The occupancy rate for people is *occasional* because the trail is used during the daytime only and during good weather. Because benches are available, some people may be in the target zone for extended periods.

Tree Conditions: One tree in the row has a large, dead branch over the trail. Examination with binoculars reveals a cavity with a fungal conk at the base of the dead branch.

Analysis: Likelihood of failure is *probable* within the next two years, and the likelihood of impacting a person is *low*, so the likelihood of failure and impact is *unlikely*. The consequences of failure are *severe* because of the human targets. The risk rating is *low*.

Mitigation Options:

Whole tree removal is not necessary because the tree is stable and healthy.

1. Prune to remove the dead branch. Even though the risk is *low*, it can be reduced further by removing the dead branch. The residual risk after pruning would remain *low*.

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2. Reduce the length of the dead branch to retain wildlife habitat. This would reduce the likelihood of failure and the likelihood of impact during the time frame. The stub may need to be removed later. The residual risk after pruning would remain *low*.
3. Retain and reassess. There will be no change to the likelihood of failure, impact, or consequences. The residual risk would remain *low*.

Reporting: A written report was submitted to the park tree risk manager.

The park manager decided to have the dead branch removed.

Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Photos by Julian A. Dunster

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Summary

Mitigation is the process of reducing risk. Actions to mitigate risk can be tree based, most frequently to reduce the likelihood of failure, or they can be target based, to reduce the likelihood of impact or the consequences. In most cases, recommending mitigation is part of the tree risk assessment process. Estimating the residual risk for each mitigation option is helpful for the tree risk manager to make an informed decision. The tree risk manager decides what actions to take based on their risk tolerance. With some *extreme*-risk trees, mitigation may involve the immediate restriction of use within the target zone before removing the tree.

Key Concepts

1. Mitigation recommendations should be reasonable and proportionate, balancing the risk and benefits of the tree.
2. Actions to mitigate risk can be tree based, most frequently to reduce the likelihood of failure, or they can be target based, to reduce the likelihood of impact or the consequences.
3. Target-based mitigation options include moving the target or restricting access to the site. It may be appropriate in some cases to create wildlife trees or manage very old trees as veteran trees or heritage trees. These options are often combined with site restrictions when the trees are located in public areas.
4. Tree-based mitigation options include pruning, installation of structural support systems, and lightning protection. Site modifications can improve growing conditions or reduce the tree's exposure to loads, and the use of tree growth regulators can sometimes extend mitigation periods.
5. At times, tree removal may be the appropriate mitigation action, but it should not be the default mitigation action.
6. Residual risk is the risk remaining after mitigation. The tree risk manager decides what level of residual risk they can accept. If the residual risk exceeds their acceptable risk level, that treatment option may not be the best course of action.
7. With populations of trees, mitigation may require prioritization. It may be possible, based on an assessor's knowledge, to offer additional guidance to the risk manager.
8. The timeline for implementing mitigation actions to reduce risk varies with the degree of risk: the greater the risk, the shorter the timeline.
9. It is the responsibility of the risk assessor to notify the risk manager in a timely manner regarding *extreme*-risk trees so that immediate mitigation can be considered.

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Reporting

Module 9

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Reporting

Module 9

Learning Objectives

- Describe the options for effectively communicating risk to the tree risk manager.
- Define each risk that is being assessed.
- Explain the key components of a written report.
- Describe effective uses of oral (verbal) reports and their limitations.
- Explain the considerations for recommending the reassessment interval.
- Discuss the limitations of the risk assessment.

Key Terms

analysis	oral (verbal) report	reporting	work order
conclusions	reassessment interval	tree risk manager	written report
limitations	recommendations		

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Introduction

After conducting a tree risk assessment, the information, **conclusions**, and **recommendations** are communicated to the **tree risk manager**, designated person, or controlling authority. The method of **reporting** should be specified in the scope of work.

The preferred reporting method is a written report that clearly presents the findings, creates a written record, and can reduce misunderstandings between the tree risk assessor and the tree risk manager. In some instances, however, the report may be oral (verbal) or videographic. A combination of oral—often at the site—and written communications can help interpret the tree risk manager's response to the assessment and provide a record of the risk assessor's observations and recommendations. The tree risk assessor should follow up oral reports with an emailed or written confirmation to the tree risk manager.

A work proposal or **work order** with a recommendation for risk mitigation may also be considered a type of risk assessment report. It is important to retain copies of all risk assessment reports and supporting evidence such as photographs.

The communication process needs to be clear, unambiguous, and readily understandable to the person receiving the information. Avoid overly complex descriptions and technical jargon when communicating with people unfamiliar with the terms. It may be helpful to include a short glossary of terms within written reports. At the end of the communication, regardless of its form, all of the key points (see lists provided in this module) should be clearly presented to the tree risk manager.

Written Reports

Written reports range in length from short to long and in content from simple to comprehensive depending on the assignment, the complexity of the situation, and the tree risk manager's requirements. Examples of written reports include a simple memo or email, a work order, or a detailed report. A memo or email can be used as a quick confirmation of oral communications.

Definitions of Some Key Terms

Several key terms are required for understanding tree risk reporting. Below is a partial list of these terms. Additional terms are defined in the module, and a more comprehensive list can be found in the Glossary.

limitations—factors that limit the precision, applicability, or extent of a tree risk assessment.

oral report—verbal report; results of the tree risk assessment delivered to the tree risk manager orally.

reassessment interval—recommendation for the next tree risk assessment or the number of tree risk assessments per given unit of time (e.g., once every three years).

reporting—presenting the tree risk manager with a summary statement describing the results of a tree risk assessment.

written report—a document delivered in print or electronic format, containing the results of a tree risk assessment.

"As we discussed on site yesterday, the branch on the maple in your front yard is likely to fail within the next year and strike your house causing significant damage, resulting in high risk. I recommend removing the branch as soon as practical."

"Based on what we discovered on site this morning, the codominant stem on the oak in your backyard presents a low risk within a three-year time frame and I do not recommend tree removal."

Even simple memos or emails like the ones above, if used, should contain the date of the discussion, the site location, time frame, levels of risk, recommendations for mitigation, and scheduling of work and reassessment (if appropriate).

Detailed written reports are another common approach for reporting on a tree risk assessment.

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Reports should document a systematic process, **analysis**, and recommendations or options for mitigation.

A typical limited visual assessment (Level 1) report includes:

- client (tree risk manager) name and contact information;
- tree risk assessor name, contact information, and credentials;
- description of the scope of work;
  - objectives of the assessment
  - location and of the tree(s) assessed and/or tree selection criteria,
  - details of the assessment (e.g., drive-by, walk-by, fly-over, Google Street View™), and[1]
  - list of specified conditions or conditions that were considered
- date(s) of assessment;
- locations of trees that were identified within the selection criteria;
- type of mitigation for each selected tree (risk rating is optional);
- recommendations for higher level of assessment, if included in the scope of work;
- recommendations for reassessment (frequency, level, and type), if appropriate; and
- limitations of the assessment.

A typical basic assessment (Level 2) report includes:

- client (tree risk manager) name and contact information;
- tree risk assessor name, contact information, and credentials;
- description of the scope of work;
  - objectives of the assessment
  - methodology used (e.g., ISA BMP)
  - level of assessment (i.e., basic) and details of the method (e.g., "Basic assessment, using a mallet and a probe"), and
  - location and/or identification of the tree(s) assessed
- date of assessment;
- targets assessed, occupancy rates, likelihood of impacting the target(s), likely consequences of failure, and time frame;
- site factors;
- documentation of the likelihood of failure, such as a list of tree conditions, structural defects, and indicators of response growth that were observed; time frame considered; and measurements, if recorded;
- risk rating, including information on specific failure type/target combinations and overall risk rating;
- recommendations for higher level of assessment, if appropriate;
- options and/or recommendations for mitigation;
- residual risk information, if appropriate;
- recommendations for reassessment, if appropriate; and
- limitations of the assessment.

A Level 2 report that employs the ISA's BMP matrices should include the time frame for the risk assessment, the likelihood of failure, the likelihood of the tree part impacting a target, and the consequences of the failure and impact.

Level 3 advanced assessment reports describe the work performed and results of the work as defined in the scope of work. The scope of work may call for only providing the data collected, or it may be used to modify or verify an existing basic assessment.

Oral Reports

A discussion with the tree risk manager about tree risk and their tolerance for risk can be effective and timely. Discussing risk factors with the tree risk manager could help them determine an acceptable risk threshold. Management options and the pros and cons of each option may also be discussed.

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International Society of Arboriculture

Figure 9.1 Discuss risk factors with the tree risk manager and help them determine a risk threshold at which they are comfortable. Also discuss risk management options and the pros and cons of each option.

Julian A. Dunster

Figure 9.2 Using software to crop, adjust exposure, and annotate images (red arrows) can improve their quality. Under no circumstances, however, should the images be altered to change their content.

Then, in the follow-up written report, briefly describe the options presented and identify and explain the preferred option. A work order describing the orally agreed upon risk mitigation option can serve as documentation.

Oral reports allow for immediate action and feedback, eliminating the time-consuming process of writing a report and waiting for the recipient to read and consider it. If the mitigation action is taken following an oral report ("the branch has now been removed"), then the message has been received and acted on. Those mitigation actions may then become part of a later written report.

An oral report can also be an important first step in informing the tree risk manager about an *extreme* risk that requires immediate attention. In that situation, follow up the oral report with a written report as soon as possible. This serves to confirm that the tree risk manager has been informed about the risk issues, and clearly show that the tree risk assessor has exercised due diligence to ensure that the tree risk manager is fully informed about the issues.

Sometimes tree risk assessors are asked to present reports at public meetings or hearings. An example is the presentation of risk assessment results and recommendations to a municipal tree board, council, or homeowners' association. An assessor could be asked to provide testimony in court or through a legal deposition based on a completed risk assessment or as an expert witness in a liability case. These possibilities underscore the need for thorough documentation during a risk assessment. Moreover, skillfully communicating the process, observations, analyses, and recommendations could make a difference in how the assessor's work is interpreted.

Oral reports are quick and simple and can be effective, but they have limitations. Later on, one or both parties may disagree about what was said or feel that the emphasis on key points was not clear enough. Providing a follow-up email or memo with a brief written summary of what was discussed and agreed to can minimize this limitation.

Video or Photographs

The use of video or photographs to document risk issues can be a useful form of additional information and data, especially when forensic investigations into tree failure and residual risk issues arise. Appropriate application of these techniques requires an understanding of equipment, photographic quality, and storage. The goal with video or photographs is to provide clear and sharply focused images that illustrate the intended condition of concern or defect.

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The technology to take videos and photographs is relatively inexpensive, widely available, and simple to use. However, obtaining good-quality images requires skill and understanding of the equipment. It is important to be systematic and thorough, and to clearly portray the issues of interest. If this approach is used, be sure to practice with the equipment beforehand, understand light conditions, and be aware of the limitations of the equipment.

On site, the use of objects of known size, such as a ruler, lens cap, or a measured length of flagging tape, can help to demonstrate the scale of important conditions. Placement of flagging tape at known heights aboveground helps to establish vertical scale or to provide a location in a landscape.

Take notes to supplement the video or photographs and be sure to document which issues apply to which tree.

Label photos and videos systematically. Using software to crop, correctly expose, and annotate images can be very helpful. Under no circumstances, however, should the images be edited in a way that changes their meaning or misleads viewers. Aspects such as contrast, exposure, and color balance can be adjusted if it helps to accurately depict the scene documented. Preservation of the original image files is critical. If changes are required to enhance the image, retain the original file and work on a copy instead. Be prepared to show how the image was treated to derive the final version. Some camera manufacturers provide image authentication software that locks in data about the image and subsequent adjustments.

Limitations of Tree Risk Assessment

Limitations of tree risk assessment arise from uncertainties related to each of the assessed factors. The scientific study of tree failure is relatively young; there is still much to learn. For example, there are advanced techniques for determining wood condition, but it is not possible to know the precise load-bearing capacity of a tree. Similarly, even if the wind speed can be measured near a tree, it is not possible to know the exact load that the tree experiences on a windy day. Because there will always be some uncertainty about the tree's load-bearing capacity and the loads it experiences, the assessment of likelihood of failure will also have uncertainties. With the likelihood of impact, it may be difficult to precisely estimate the direction of fall, or the presence and number of pedestrians or vehicles that might be struck if the tree were to fail.

Tree risk assessors perform assessments with limited information about the structural condition of the tree and the environment that affects it. For instance, stem or root decay may be present but not visible at the time of the assessment. Similarly, extreme winds that create loads greater than the tree can withstand are not easily predictable. Experience, training, and education influence how the tree risk assessor evaluates and analyzes the situation to form an opinion about what is likely to occur in the future.

Tree risk assessors should include the limitations of their assessments in the risk assessment report, including limitations of the methodology used and any limitations related to the ability to access the tree, site, or potential targets.

Risk assessment reports commonly include statements of limitations such as:

- Tree risk assessment is limited to the trees assessed and specific risk(s) of interest (e.g., tree failure), not any and all risks (e.g., lightning, tree-related conflicts).
- Tree risk assessment considers only specified targets, significant known targets, and visible or reasonably detectable tree conditions.
- Tree risk assessments represent the perceived condition of the tree at the time of assessment.
- Not all defects are detectable, and some failures are not predictable.
- The time frame for risk categorization is not and should not be considered a "guarantee period" for the risk assessment.
- Only those trees specified in the scope of work were assessed, and assessments were performed within the limitations specified.

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Reassessment

Timing of the initial risk assessment is usually not at the discretion of the tree risk assessor. However, after a tree has undergone the initial assessment, the tree risk assessor should recommend a reassessment based on the level of risk/residual risk and the goals of the tree risk manager. The time between assessments is known as the **reassessment interval**.

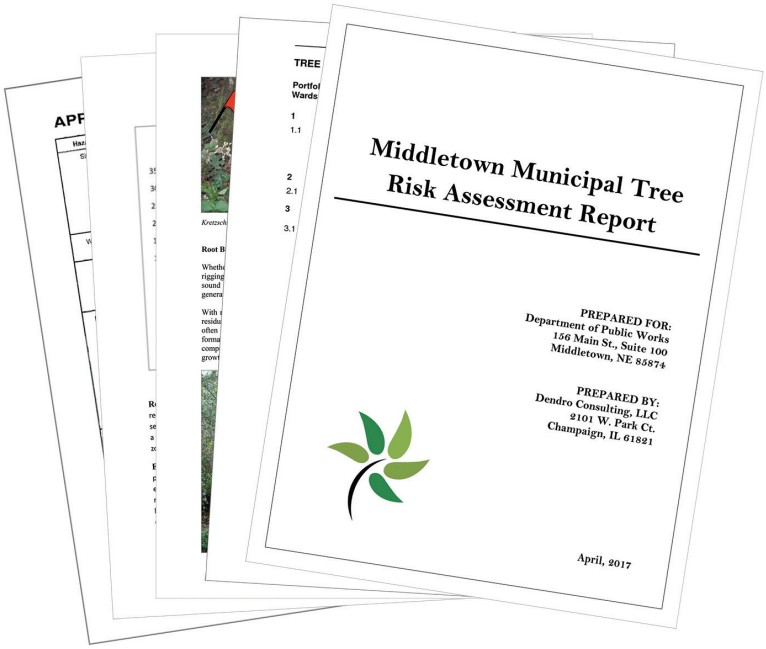

Figure 9.3 Communicating the results of the risk assessment to the tree risk manager is a critical component in the risk assessment process that can involve arboriculture, public safety, and potential legal issues. There are several ways to present this information, but the preferred approach is written communication. A detailed formal report is a sign of professionalism.

It is best to reassess trees on a recurring basis because site and tree conditions change over time. The reassessment interval typically ranges between one and five years, but may be more (or less) often, depending on target zone occupancy; the age of the tree; level of risk; tree and site conditions; system context; scale; the tree risk manager's goals, risk tolerance, and resources; regulations; and other considerations. For example, a *low*-risk tree with *rare* or *occasional* target zone occupancy may be assigned a reassessment interval of three to five years. For a *moderate*-risk tree, or even a *low*-risk tree with *frequent* target zone occupancy, a shorter reassessment interval may be recommended.

Generally, it is a good idea to assess trees near high-value targets after major storms and after site changes that result in changes to tree loads (e.g., forest clearing, building demolition), or the tree's load-bearing capacity has changed (e.g., root cutting, grade changes, hydrology changes).

The reassessment interval for municipalities, utilities, and other entities that manage large populations of trees is defined by tree risk managers and/or the controlling authority.

Public agencies, utilities, and large property managers may identify zones of similar tree populations, site usage, and facility type. The reassessment interval for each zone is then specified. Zones of higher priority are monitored more frequently than zones with lower priority.

Scheduling assessments in a specific season can aid the assessment. For instance, the crowns of deciduous trees are more easily assessed for likelihood of failure in the winter than in the summer because leaves can obscure the branch structure and unions. If a particular decay fungus produces annual fruiting bodies (e.g., conks, brackets, mushrooms) at specific times of year, but the structures then degrade or disappear, identification of the fungus will be easier if the reassessment is scheduled when fruiting bodies are present. Staggered reassessment frequencies, such as every 8 or 16 months, will allow the tree risk assessor to see the trees in different seasons.

Finally, keep in mind that all assessments represent likelihoods that become more uncertain over time because of changes in conditions. In other words, the longer the reassessment interval, the greater the uncertainty. It is therefore important to communicate to the tree risk manager the time-dependency of the assessment. In general, the greater the risk, the shorter the reassessment interval.

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CASE STUDY

November 17, 2025

Jane Smith
1234 Main St.
Pleasantown, CA

Subject: Tree Risk Assessment of Coast Live Oak

Dear Ms. Smith:

We met at the day care center you operate at 1234 Main St. on November 10 to discuss the mature coast live oak tree (*Quercus agrifolia*). The tree is in the children's play area on the west side of the building. You asked me to assess the condition of the tree and the risk it poses to staff and visitors.

On November 12, I performed a basic (Level 2) visual inspection of the tree from the ground. This letter summarizes my findings, presents an assessment of risk associated with the tree, and provides recommendations for management.

Site location, description of assignment, date of inspection, how inspection was performed, what is in report.

Description of the Tree
The coast live oak has a 30-inch trunk diameter at 3.5 feet above the ground and is 35 to 40 feet in height (Photo 1). The tree is in a circular open soil area approximately 6 feet in diameter. The area beyond the soil area is paved. The tree is not irrigated and there are no plantings beneath the canopy.

The tree's canopy appears normal in color but unusually sparse, with many small-diameter dead branches. I considered its health to be fair. It appears to have been declining for several years.

The tree is leaning slightly, and the crown is slightly heavier on the northwest side. The main trunk divides into three stems at 4.5 feet above the ground. A seam is present where bark is embedded at the attachments with the central stem (Photo 2). There are several pruning wounds with visible decay, and, in some cases, cavities (Photo 3).

Description of tree and site.

Photo 1. The subject coast live oak in day care play area, west of the building.

Photo 2. The central stem has included bark at the attachment that forms a seam.

Photo 3. Decay is visible in a 15-inch-long old wound with a cavity on the southern stem.

Annotated photographs of tree overall, and close-ups of conditions of concern.

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CASE STUDY

Daycare Coast Live Oak Assessment.
Nov. 17, 2025

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Page 2

Methodology
I followed the procedures described in Best Management Practices—*Tree Risk Assessment*, Third Edition (BMP, 2025, International Society of Arboriculture). Tree risk is defined as the combination of the likelihood of tree failure, the likelihood that people or property (target) would be struck by the failure, and the consequences of the failure.

The risk rating is derived from my professional assessment of four conditions: the likelihood of tree failure, the target use and occupancy, the likelihood of impact, and the consequences of the failure. Ratings for each of those are applied to two BMP matrices to determine the likelihood of failure and impact, and the risk rating. I based my assessment of the likelihood of failure on a time frame of 1 year, as we discussed.

Description of risk assessment methodology.

Risk Assessment
The most likely point of failure is one of the three stems. I assessed the risk associated with a stem failing and impacting either of two targets: (1) the people in the play and lunch areas and (2) the building (Table 1). If a stem fell onto the building it would cause structural damage, but the building would protect people inside of it. People in the playground and lunch area, however, would not be protected and could be injured by the falling stem and its branches.

Identification of specific targets and failure types.

Table 1. Risk Assessment of Coast Live Oak.

Part of Tree	Target	Likelihood of Failure	Likelihood of Impact	Likelihood of Failure and Impact	Consequences	Risk
Stem	People in the play and lunch area	Possible	Medium	Unlikely	Severe	Low
Stem	Building	Possible	High	Somewhat likely	Significant	Moderate

Note: Column headings use terms found in the BMP—*Tree Risk Assessment* (2025).

Summary table of tree risk ratings for two target/failure combinations.

Using the BMP methodology, I rated the likelihood of a stem failing as *possible.* The daycare center is open 12 hours a day, 6 days a week. People are likely to be present for several hours a day. I rated the occupancy as *frequent*, the likelihood of impact as *medium*, and the likelihood of failure and impact as *unlikely*. The consequences of such a failure would be *severe.* Using the BMP risk matrix, the risk rating for the stem failing and hitting a person in the playground/lunch area is *low*.

I rated the likelihood of the stem near the building failing to be *possible*. Because the building is stationary, it has a *constant* occupancy rate. Therefore, the likelihood of impact would be *high,* and the likelihood of failure and impact is *somewhat likely*. Given the size of the stem and height of the tree, the consequences of failure onto the building are *significant.* It would not destroy the building but would require significant repairs. The overall risk rating for stem failure onto the building is *moderate*.

For each of two target/failure combinations, ratings and descriptions of likelihood, occupancy, likelihood for failure and impact, consequences, and risk.

Recommendations
Management of declining trees is difficult because there can be many causes and often there is limited response to treatment. My visual inspection provides limited information about the health of the root system and the internal condition of the trunk and branches. I recommend further investigation to determine what mitigation options are available to improve tree health and structural stability.

Recommendations for risk mitigation.

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CASE STUDY

Daycare Coast Live Oak Assessment.
Nov. 17, 2025

Famous Tree Consulting
Page 3

Following are my recommendations for further investigation if you want to reduce the risk and retain the tree, or if you prefer to remove the tree and eliminate the risk.

1. **Examine the tree further to determine risk mitigation treatments.**
   - Perform an advanced inspection of the root collar, trunks, and scaffold branches to determine the extent of internal decay. If decay is extensive, removing the tree may be prudent. If decay is relatively small, preservation can be considered with pruning to reduce the weight on the stems.
   - Perform an aerial inspection to identify defects not observable from the ground that would change the likelihood of stem and branch failure.
   - To reduce the likelihood of stem and branch failure, consider pruning to shorten long lateral branches, particularly those that could strike the building. This would reduce the risk rating to *low*, but it would also result in a smaller, misshapen crown.
   - Schedule annual inspections by a Tree Risk Assessment Qualified Arborist to evaluate health and structural stability and the need for additional treatments. Inspect the tree after any storms to evaluate damage and structural changes.
   - If the root collar inspection reveals healthy roots, I will provide appropriate treatment recommendations to improve tree health.
2. **Remove the tree now.**
   - The only way to eliminate the risk is to remove the tree. The advantages of removing the tree should be considered with the loss of benefits the tree provides, such as shade and wildlife habitat.

Description of actions to manage risk of this tree.

Limitations

My risk assessment was limited by relying on a visual inspection from the ground. I did not inspect the roots below ground, or the internal condition of the tree. There may be defects in the upper crown that I could not see from the ground.

Trees change over time. My inspection represents the condition of the tree at the time of inspection. Annual tree inspections are recommended to identify changes to tree health and structure. In addition, trees should be inspected after storms of unusual severity to evaluate damage and structural changes. Initiating these inspections is the responsibility of the client and/or tree owner.

Furthermore, we cannot predict all failures. Wind forces, for example, can exceed the strength of wood causing branches and trunks to break in unexpected ways. Wind forces coupled with rain can saturate the soil, reducing its ability to hold roots, and causing trees with no visible defects to blow over.

Limitations of the risk assessment and need for reinspection.

Please feel free to contact me with any questions. I look forward to hearing from you.

Sincerely,

Linden Forest

Linden Forest, Consulting Arborist
ISA Certified Arborist No. XY-0211A
ISA Tree Risk Assessment Qualified

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Summary

Communicating the risk assessment results to the tree risk manager is an important step in tree risk assessment. The results and recommendations form the basis for subsequent risk management activity. There are several ways to accomplish this, but the preferred approach is a written report. Whatever method is selected, the report must be clear and unambiguous.

Key Concepts

1. After conducting a tree risk assessment, communicate the information, conclusions, and recommendations to the tree risk manager. The preferred method is a clear and concise written report because it documents findings and recommendations.
2. Some of the key elements in a risk report are the location or identification of the tree(s) assessed, time frame, level of assessment, targets, risk rating, options and/or recommendations for mitigation, residual risk, and limitations of the assessment.
3. Having a discussion with the tree risk manager about the tree risk assessment can be a timely and effective method of communication. A discussion can help them determine a risk threshold and preferred mitigation option.
4. Oral reports are quick and simple, but they have limitations. Following up with a written summary of the discussion can reduce the potential for misunderstandings.
5. Limitations of tree risk assessments arise from uncertainties related to trees, defects and conditions, and the loads to which they are subjected. Include limitations of the assessments in the risk assessment report, as well as the limitations of the methodology used, and any limitations related to the ability to access or assess the tree, site, or potential targets.

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Appendix I
Using the ISA Basic Tree Risk Assessment Form

The *Basic Tree Risk Assessment Form* is a guide for collecting, recording, and analyzing tree risk assessment information. It is intended for use in a basic (Level 2) tree risk assessment. Limited visual (Level 1) or advanced (Level 3) assessments require the use of different forms or datasheets that are not presented in this publication.

This *Basic Tree Risk Assessment Form* supersedes any previous version used in the TRAQ class. Tree risk assessors are welcome to use this *Form* in their practice of tree risk assessment. For personal or corporate use, this *Form* may be used as presented or adapted for specific requirements.

The *Form* can also be useful when developing a written report and is often attached to reports to detail assessment observations and analyses. The *Form* alone is not intended to serve as a report; however, some municipalities require submission of the *Form* when applying for permits.

The following is an item-by-item description of the information that is intended to be entered on the *Form*. Space is provided in several locations to write comments for conditions that are not included elsewhere on the *Form* or for items that need additional explanation. *It is not necessary to mark every box or to fill in every line on this Form.*

PAGE 1—DATA COLLECTION

Section 1: Assignment and General Tree Information

ISA **Basic Tree Risk Assessment Form** Assessor _____

Client _____ Date _____

Address/Tree Location _____ Tools _____

Tree Species _____ Tree # _____ DBH _____ Height _____ **Time Frame** _____ years/months

This section is for documenting the assignment and collecting general information. Some parts of this section may be completed prior to the site visit.

Assessor—your name and the names of anyone working with you as a tree risk assessor.

Client—name of the person or entity who hired you to perform the assessment. Typically, this is the tree risk manager.

Date—date of the site visit/tree inspection when data is collected.

Address/Tree Location—the physical address, GPS coordinates, or other location description of the tree and/or the location of the tree on the property, such as "backyard" or "between street and sidewalk." For example, "411 Pine Street, Oakville. Large tree left side of driveway."

Tools—list of tools used in the assessment such as "mallet" or "binoculars." If no tools were used, write "none" or leave blank.

Tree Species—the common and/or scientific name of the tree; cultivar, if known.

Tree #—if the tree has an inventory tag with a descriptor (usually a number), it should be entered here. If a group of trees without tags are assessed, they may be assigned a sequence number in this space.

DBH—trunk diameter at breast height measured in inches or centimeters. The height of this measurement is standardized by country, region, or municipality (in the United States, 4.5 ft [1.37 m]; IUFRO standard is 1.3 m above ground). The height of this measurement can be adapted based on tree form or site conditions (e.g., low branches, swelling, lean, slope). The unit of measurement (i.e., inches, centimeters) is included with the diameter.

Height—total tree height is visually estimated or measured. The unit of measurement (i.e., feet, meters) is included with the height. If measured, the tool used for this measurement should be recorded on the Tools line.

Time Frame—the period for which an assessment is defined, typically between one and five years. A number is entered and the appropriate unit (years/months) is circled.

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Section 2: Target Description

Target #	Target Description Be specific, only one target per line.	Target Zone Check one box per target.				Occupancy Rate during time frame:			
		Drip line	1 X Ht	1.5 X Ht	>1.5 X Ht	Rare	Occasional	Frequent	Constant
1	First priority target (e.g., people near the tree)								
2	Second priority (e.g., people, structures, vehicles)								
3	Third priority (e.g., structures, vehicles)								

This section is for documenting targets—people, property, or activities that could be injured, damaged, or disrupted by a tree failure—within the striking distance (target zone) of the tree part. Three lines are provided; additional targets can be listed on a separate form.

Target #—the target number column is provided to associate a number with the target description so that the target description does not need to be rewritten in the Branches; Trunk; and Roots Collar, Roots, and Soil sections below and in the table on the second page of this form. Target 1 is typically the most important target considered.

Target Description—a brief description of the target such as "people near the tree," "house," "children in a play area," or "cars on a high-traffic street." Specific information should be provided. Entries such as "street" or "sidewalk" are *not* specific enough. Grey text descriptions already on the Form such as "First priority target (e.g., people near the tree)" are prompts to encourage prioritizing targets, with the most important target listed first, and including a brief description of the target.

Target Zone—identify where the targets are in relation to the tree or tree part that may impact the listed target. Only one box needs to be checked:

> **Drip line**—target is underneath the crown of the tree.
>
> **1 × Ht**—target is within striking distance if the trunk or root system of the tree fails (one times the tree height).
>
> **1.5 × Ht**—target is within striking distance if the trunk or root system of the tree fails and there are dead or brittle branches that could shatter and fly from the failed tree (up to 1.5 times tree height).
>
> **>1.5 × Ht**—the target is no closer to the trunk than 1.5 times the tree height but may be struck, for example, if the tree falls down a slope.

Occupancy Rate—an estimated amount of time the target is within the target zone within the specified time frame. Only check one box:

> **Rare**—the target zone is not commonly used by people or other mobile/movable targets.
>
> **Occasional**—the target zone is occupied by people or other targets infrequently or irregularly.
>
> **Frequent**—the target zone is occupied for a large portion of the day or week.
>
> **Constant**—a target is present at nearly all times, 24 hours a day, 7 days a week.

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Section 3: Site Conditions

Site Conditions

Concerns: _____ ☐ None

Site changes: ☐ None ☐ Grade change ☐ Site clearing ☐ Changed hydrology ☐ Other _____

This section is for documenting site conditions that may influence the likelihood of tree failure.

Concerns—List site factors affecting wind load, including site elevation, slope, aspect (compass direction of slope), and hilltop locations. History of failures that are visible at the site can be included here (history of branch failures on this tree are noted in the Branches section, below).

Site changes—factors affecting the root system of the tree or a change in exposure of the tree to wind.

None—no evidence of recent site changes.

Grade change—soil was added or removed from the site.

Site clearing—adjacent trees, which may have blocked the wind, have recently been removed or significantly reduced.

Changed hydrology—changes have been made that affect water flow in or out of the site.

Other—additional site conditions that may affect the likelihood of failure that were not previously listed or further descriptions of site changes.

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Section 4: Crown

Crown

Foliage: ☐ None (dead) ☐ None (seasonal) Normal _____% Chlorotic _____% Necrotic _____%
Tree Health: ☐ Dead ☐ Poor ☐ Fair ☐ Good
Health concerns: _____ ☐ None
Density: ☐ Sparse ☐ Average ☐ Dense ☐ Vines/mistletoe/moss_____
Relative size crown/trunk: ☐ Small ☐ Medium ☐ Large ☐ Unbalanced ☐ Crown dieback ☐ Excessive end weight
Wind Exposure: ☐ Protected ☐ Partial ☐ Full ☐ Wind funneling Load concerns/recent changes _____
Pruning: ☐ Topped ☐ Thinned ☐ Lion tailed ☐ Raised ☐ Other _____ Live crown ratio (LCR) _____%

This section is for documenting conditions of the tree crown including both tree health and information needed to assess the potential loads on the crown.

Since the information in this section may also apply to branches, trunk, or roots, no likelihood of failure decisions are made here; they are instead made within the specific part description sections, below.

Foliage—leaf size and color are indications of tree health. If not sure of the normal condition of this species, compare with other specimens of the same species in the area:

None (dead)—a tree that has dropped its leaves because it is dead.

None (seasonal)—a deciduous tree that has dropped its leaves in the dormant season.

Normal—percentage of foliage that is a normal color for the species in the area.

Chlorotic—percentage of foliage that is yellowish green to yellow.

Necrotic—percentage of dead foliage in the crown.

Tree Health—this is a general rating of tree health based on foliage color (previous item), crown density, leaf size, pest issues, tree or twig growth rate, crown dieback, and other factors.

Dead—the tree is totally or mostly dead.

Poor—the tree has major health problems and may not be expected to live for more than a few more years.

Fair—the tree has at least one health problem that may or may not be correctable.

Good—the tree does not appear to have any serious health problems.

Health concerns—when health concerns are identified such as when the Poor or Fair *Tree Health* boxes are marked, the symptoms or cause of the problem can be entered here.

None—if there are no tree health concerns, mark this box.

Density—the relative wind and light transparency of the crown:

Sparse—crown allows a large degree of wind and light penetration; varies with species.

Average—indicates a normal density for the species and location, moderate wind and light penetration.

Dense—crown does not allow much light or wind penetration.

Vines/mistletoe/moss—mark the box if vines, mistletoe or moss are present at levels where they would be expected to significantly increase load or wind resistance. Moss refers to bryophytes, Spanish moss, ball moss, or epiphytes. The line is provided to describe or name the epiphyte.

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Relative size crown/trunk—comparison of the tree's crown size to the trunk diameter. Classify as small, medium, or large.

Unbalanced—mark box if branches and foliage in the crown are not uniformly distributed, mostly on one side of the tree.

Crown dieback—there are dead branches or a significant number of dead twigs in the crown.

Excessive end weight—the foliage is mainly concentrated on the outer third of the branch(es). This may be the result of lions-tail pruning or it may be a characteristic of the species.

Wind Exposure—How exposed the tree crown is to wind:

Protected—least exposure to wind. Protected by trees or structures surrounding the tree.

Partial—some wind exposure. The tree is partially protected by other trees or structures near the tree.

Full—maximum exposure to wind.

Wind funneling—wind may be "funneled" or "tunneled" by buildings, canyons, or large stands of trees toward this tree so there will be a greater wind load. This may include trees at the corners of buildings.

Load concerns/recent changes—recent (last few years) or planned (next few years) changes at the site that may significantly affect the load on this tree. Examples include removing nearby trees or buildings, or reduction in loads from the growth of other trees near this tree.

Pruning—is there evidence that the tree has been pruned? If there is, describe the pruning as:

Topped—inappropriate pruning technique used to reduce tree size; characterized by internodal cuts.

Thinned—live, interior branches were pruned to reduce crown density.

Lion tailed—inappropriate pruning practice removing an excessive number of inner and/or lower lateral branches.

Raised—removal of lower branches to provide clearance.

Other—trees pruned for other objectives/systems may be noted here. This includes reduction pruning, structural pruning, pollarding, espalier, and vista pruning.

Live crown ratio (LCR)—the ratio of the height of the live crown to the height of the entire tree. This can be calculated [LCR = (crown height/tree height) × 100] or visually estimated. Enter a percentage of the tree height.

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Section 5: Branches

Branches

☐ No concerns ☐ Dead branches _____% overall Max. dia. _____
☐ Broken/hanging # _____ Max. dia. _____ ☐ Overextended
☐ Poor taper ☐ Weak attachments _____
☐ Previous branch failures _____ ☐ Similar branches present
☐ Structural support _____ ☐ Excessive sprouts ☐ Cracks
☐ Sapwood/heartwood decay ☐ Conks/mushrooms _____
☐ Cavity opening _____ ☐ Response growth _____

Main Branch and Crown Failure Types:

Failure Type 1: _____
Part size _____ Fall distance _____ Load: ☐ Low ☐ Med ☐ High
Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Failure Type 2: _____
Part size _____ Fall distance _____ Load: ☐ Low ☐ Med ☐ High
Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

This section is for documenting specific branch defects and conditions. Information on trunk or root issues should not be recorded here.

No concerns—if no significant defects or conditions were identified, this box should be marked. If this box is marked, no additional information is required in the **Branches** section of this form.

Dead branches—mark the box if there are dead twigs or branches in the crown. If marked, follow with a percentage (%) of the total number of branches within the crown that are dead, and an estimate of the basal diameter of the largest dead branch (Max. dia.) including the unit of measurement (i.e., inches, centimeters).

Broken/hanging—broken or cut branches remaining in the crown. Record the number (#) and an estimate of the basal diameter of the largest broken or hanging branch (Max. dia.).

Overextended—mark the box if there are branches that extend beyond the tree's canopy or that are excessively long with poor taper.

Poor taper—mark the box if there are branches where their diameter does not change much along their length.

Weak attachments—branches that are codominant or have a basal diameter similar to attached stems or branches, or that have included bark or splits at or below the union. Mark the box if present and describe.

Previous branch failures—mark the box if there is evidence of previous branch failures and describe briefly. Check "Similar branches present" if there are other branches that have similar characteristics and may be more likely to fail.

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Structural support—mark the box if there is a support system within the crown such as a cable, brace rod, or other device.

Excessive sprouts—mark the box if there are numerous sprouts associated with branch breakage or pruning that may be prone to failure or add significant load.

Crack(s)—separation in the wood in either a longitudinal (radial, in the plane of ray cells) or transverse (across the stem) direction.

Sapwood/heartwood decay—mark the box if there is evidence of decay.

Conks/mushrooms—fungal fruiting structures (i.e., mushrooms, brackets); definite indicators of decay. Mark the box if present and name or describe.

Cavity opening—from the outside of the branch into the heartwood area from decay or animal damage. Line is to record the width of the opening or other descriptor.

Response growth—reaction wood, wound wood or additional wood grown to increase the structural strength of the branch near a defect or condition of concern. Name or describe on the following line.

Main Branch and Crown Failure Types—in this section there is space to describe two failure types, Failure type 1 and Failure type 2, and two targets for each of those two failure types. If there are no anticipated branch failures or if there is only one anticipated branch failure, put a dash following Failure type, write N/A (not applicable), or "none" on the line. If there are more than two anticipated branch failure types of concern, additional forms may be used to describe and classify.

The information under both Failure types (Failure type 1 and 2) is identical so will only be described once.

Failure Type (1 or 2)—on this line provide a short description of the most likely cause for a branch failure. This could be "dead branch," "codominant branch," "decayed branch," "overextended branch with excessive load," or other description.

> **Part size**—this is the basal diameter of the branch expected to fail or the diameter at the expected point of failure. Include units of measurement (i.e., inches or centimeters).
>
> **Fall distance**—the distance that the failed branch will fall before hitting a target. Typically this is estimated from the highest point of the branch to the target. Include units of measurement (i.e., feet, meters).

Load—this is the load on the branch that is expected to fail relative to the size of the branch.

> **Low**—there is little load on the branch such as when the branch is dead and there are no leaves attached.
>
> **Medium**—there is some load on the branch such as from leaves, twigs, or other branches.
>
> **High**—there is significant load on the branch such as a large branch with many leaves, twigs, and branches attached, or a branch that is fully exposed to wind, rain, snow, or ice loading.

Likelihood of Failure—categorize the likelihood of failure (*Improbable*, *Possible*, *Probable*, or *Imminent*) for the crown part or branch that was identified. This information will be transferred to the Risk Categorization table on the second page of this form. Mark only one box.

There are two **Target #** boxes below **Likelihood of Failure** that can be used for rating two different targets. If there is only one target present, only one box should be completed. If there are more than two, additional forms may be used.

Target #—targets were described in the second section (**Target Description**) of this form. Rather than repeating that description, the number in the left column under the **Target Description Target #** should be entered here.

Protection—if there is anything that will protect the target from damage if the branch fails, it should be listed here. Common examples include lower branches, adjacent trees, houses, cars, and shelters.

Likelihood of Impact—if the branch were to fail, the likelihood of striking the target should be categorized here (*Very low, Low, Medium,* or *High*). Mark only one box.

Consequences—if the branch were to fail and strike the target, the anticipated consequences should be categorized (*Negligible, Minor, Significant,* or *Severe*). Mark only one box.

Information from this section should be transferred to the second page of the form to categorize tree risk. Much of this information can also be used to categorize residual risk.

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Section 6: Trunk

Trunk

☐ No concerns ☐ Codominant stems # _____ ☐ Included bark
☐ Decay ☐ Conks/mushrooms _____ ☐ Cavity opening _____
☐ Decay depth _____ ☐ Poor taper ☐ Lean ____° ☐ Corrected
☐ Dead/missing bark ☐ Cracks ☐ Ooze ☐ Lightning damage
Other _____ Response growth _____
Main Trunk Failure Type: _____
Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe
Target # _____ Protection _____
Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High
Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

This section is for documenting specific defects and conditions that are identified in the trunk.

No concerns—if no significant defects or conditions were identified on the trunk, this box should be marked. If this box is marked, no additional information is required in the **Trunk** section of this form.

Codominant stems—mark the box if two or more stems of similar diameter originate from the same union. Record the number (#) of codominant stems originating from the union.

Included bark—bark that is embedded in a union between codominant stems.

Decay—mark the box if there is evidence of decay. This includes heartwood decay, sapwood decay, soft rots, canker rots, or other deterioration of the wood.

Conks/mushrooms—fungal fruiting structures (i.e., mushrooms, brackets); definite indicators of decay. Mark the box if present and name (if known) or describe.

Cavity opening—wood may be missing due to decay, wildlife damage, termites, or other causes. Record the percentage (%) of the trunk circumference that has missing wood (% circ.) This can be a visual estimate or measured.

Decay depth—mark the box if there is a cavity opening, enter the distance from the outside of the bark to the sound wood at the other side of the cavity. This may be determined visually or using a probe.

Poor taper—mark the box if the diameter of the trunk does not change much along its length.

Lean—angle of the trunk measured from vertical. Record the degree of lean. This can be visually estimated or measured with a digital level such as found in cell phone apps.

Corrected—mark the box if the tree has corrected the lean with new growth.

Dead/missing bark—mark the box if bark is dead or missing.

Cracks—separation in the wood in either a longitudinal (radial, in the plane of ray cells) or transverse (across the stem) direction.

Ooze—liquid seeping out of the bark, often associated with cracks or other wounds

Lightning damage—often evidenced by a centrally located line of sapwood damage and bark removal on either side in a spiral pattern on the trunk or branch.

Other—other defects or conditions that may affect the likelihood of failure.

Response growth—reaction wood, woundwood, flexure wood, or additional wood grown to increase the structural strength of the stem near a noted defect or condition. Name or describe on the line.

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Main Trunk Failure Type—in this section there is space provided to describe the most likely cause for a trunk failure. This could be "excessive heartwood decay," "codominant stems," "dead trunk," or other description.

If the trunk is not expected to fail within the time frame, put a dash following Failure Type, write N/A (not applicable), or "none" on the line. If there is more than one significant anticipated trunk failure type of concern, additional forms may be used to describe and classify.

Likelihood of failure—categorize the likelihood of failure (*Improbable, Possible, Probable,* or *Imminent*) that was identified for the trunk. This information will be transferred to the **Risk Categorization** table on the second page of this form. Mark only one box.

There are two **Target** boxes below **Likelihood of Failure** that can be used for rating two different targets. If there is only one target present, only one box should be completed. If there are more than two, additional forms may be used.

Target #—targets were described in the second section of this form. Rather than repeating that description, the number in the left column under **Target #** can be entered here.

Protection—if there are any structures that will protect the target from damage if the trunk fails, it should be listed here. Common structures include adjacent trees, houses, and cars.

Likelihood of Impact—if the trunk were to fail, the likelihood of striking the target should be categorized here (*Very low, Low, Medium,* or *High*). Mark only one box.

Consequences—if the trunk were to fail and strike the target, the anticipated consequences should be categorized (*Negligible, Minor, Significant,* or *Severe*). Mark only one box.

Information from this section should be transferred to the second page of the form to categorize tree risk. Much of this information can also be used to calculate residual risk by changing the factors that will be mitigated.

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Section 7: Root Collar, Roots, and Soil

Root Collar, Roots, and Soil

☐ No concerns ☐ Collar buried/not visible Depth _____

☐ Stem girdling _____ ☐ Fill soil _____

☐ Significant root damage or decay ☐ Conks/mushrooms _____

☐ Cut, distance from trunk _____ ☐ Root plate lifted _____

Soil: ☐ Often saturated ☐ Limited volume ☐ Pavement/Compaction

Response growth _____

Main Root / Soil Failure Type: _____

Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

In this section, information on specific defects and conditions are identified in the root collar, roots, or soil.

No concerns—if no significant defects or conditions were identified, this box should be marked.

Collar buried/not visible—mark box if the root collar is not visible.

> **Depth**—if practical, determine and record the depth from the soil line to the top of the buttress roots.

Stem girdling—restriction to growth of the trunk or buttress roots from mechanical damage, straps, ropes, or roots. Describe on the line provided.

Fill soil—mark box if soil has been added to the site within the dripline of the tree. Describe or provide depth of fill if known. If against the trunk, also mark Collar buried/not visible.

Significant root damage or decay—signs of root damage such as visible dead roots, cut roots, missing root, fungal fruiting structures.

Conks/mushrooms—fungal fruiting structures are attached to roots or root collar. Fungal fruiting structures away from the trunk in the turf or mulch may or may not be related to root decay. Mark the box if structures are present and identify/describe on the line.

Cut, distance from trunk—evidence of root cutting such as a trench or soil cut. Estimate and record the distance from the trunk to the cut.

Root plate lifted—soil cracking or lifting indicates the tree has been moving excessively, usually in high winds. Mark the box if present, and describe or record height of the lifted root plate edge, including units of measurement (inches, centimeters).

Soil—condition of the soil that may affect the likelihood of failure.

> **Often saturated**—soil is often wet indicating possible soil depth limitations for root growth, root decay, and lack of soil strength.
>
> **Limited volume**—soil volume available for root development is limited by infrastructure, high water table, rocks, or other cause.
>
> **Pavement/compaction**—soil volume is limited by pavement or other infrastructure or soil compaction within the dripline.

Response growth—reaction wood, woundwood, flexure wood, or additional wood grown to increase the structural strength of the stem near a noted defect or condition. Name or describe on the line.

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Main Root/Soil Failure Type—in this section there is space to describe the main condition of concern for root collar, root, or soil related failure. If failure is not expected within the time frame, put a dash following Failure Type, write N/A (not applicable), or "none" on the line. If there is more than one significant anticipated failure type of concern, additional forms may be used to describe and classify.

Provide a short description of the most likely cause for failure. This could be "excessive root decay," "excessive soil moisture," "dead roots," or other description.

Likelihood of Failure—categorize the likelihood of failure (*Improbable, Possible, Probable,* or *Imminent*) for the root collar, roots, or soil concern that was identified. This information will be transferred to the **Risk Categorization** table on the second page of this form. Mark only one box.

There are two **Target** boxes below **Likelihood of Failure** that can be used for rating two different targets. If there is only one target present, only one box should be completed. If there are more than two, additional forms may be used.

Target #—targets were described in the second section of this form. Rather that repeating that written description, the number in the left column under **Target #** can be entered here.

Protection—if there is anything that will protect the target from damage if the tree fails, it should be listed here. Common examples include adjacent trees, houses, cars, and shelters.

Likelihood of Impact—if the roots or soil failed, the likelihood of striking the target should be categorized here (*Very low, Low, Medium,* or *High*). Mark only one box.

Consequences—if the roots or soil were to fail and the tree strikes the target, the anticipated consequences should be categorized here (*Negligible, Minor, Significant,* or *Severe*). Mark only one box.

Information from this section is transferred to the second page of the *Form* to categorize tree risk. Much of this information can also be used to calculate residual risk by changing the factors that will be mitigated.

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PAGE 2—RISK CATEGORIZATION, ANALYSIS, AND MITIGATION

The second page of the *Form* is used to summarize the data, analyze the data, categorize tree risk, and describe how the risk should be mitigated. It also provides space for additional notes or comments for any section. Use an additional form or separate sheets if more space is needed.

Section 8: Risk Categorization and Analysis

Risk Categorization and Analysis

Tree Part Branches, Trunk, Root Collar, Roots, or Soil	**Failure Type** Dead, Hanging, Decay, Crack, etc.	**Target** Description or Number	**Likelihood of Failure**				**Likelihood of Impact**				**Failure and Impact** from Matrix 1				**Consequences**				**Risk Rating** from Matrix 2
			Improbable	Possible	Probable	Imminent	Very low	Low	Medium	High	Unlikely	Somewhat	Likely	Very likely	Negligible	Minor	Significant	Severe	

Overall tree risk rating: ☐ Low ☐ Moderate ☐ High ☐ Extreme

This *Form* uses the risk categorization methodologies presented in ISA's Best Management Practices—*Tree Risk Assessment*. The data table provided is a tool to summarize the data entered on the first page of the *Form* and analyze risk. Risk can be categorized for up to four different **Failure Types** found in the tree. **Additional Failure Types** may be included on an additional form. One line should be completed for each **Failure Type/Target** combination. Two columns (**Failure and Impact**, and **Risk Rating**) are shaded in gray to emphasize that these are determined through the use of the two matrices, printed below.

Tree Part—specify which part of the tree (Branches, Trunk, Root Collar, Roots, or Soil) is associated with the **Failure Type** of concern. For example, it may be the broken branch over the house and an overextended branch over the driveway. The entries in the **Tree Part** column would both be "branch." Other options for this column include "trunk," "roots," and "soil."

Failure Type—identify the concern(s) with the tree part listed. The information should correspond to one of the **Failure Types** on the first page. An example would be "large, dead branch."

Target (Description or number)—specify the target number from page 1, section 2, or write a brief description that is consistent with the previous target description. An example would be "house" or "people near the tree."

Likelihood of Failure—transfer the selected likelihood of failure information from page 1, section 5, 6, or 7 to the *Improbable, Possible, Probable*, or *Imminent* box that corresponds to the **Tree Part**, **Failure Type**, and **Targets** listed. Select only one box per line.

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Likelihood of Impact—transfer the selected **Likelihood of Impact** information from page 1, section 5, 6, or 7 to the *Very low, Low, Medium*, or *High* box that corresponds to the **Tree Part**, **Failure Type**, and **Target** listed. Select only one box per line.

Failure and Impact—use Matrix 1—the Likelihood matrix—to combine the **Likelihood of Failure** and the **Likelihood of Impact** to determine the Likelihood of Failure and Impact. Mark the category determined as *Unlikely, Somewhat likely, Likely*, or *Very likely*. Select only one box per line.

Consequences—transfer the selected **Consequences** information from page 1, section 5, 6, or 7 to the *Negligible, Minor, Significant*, or *Severe* box that corresponds to the **Tree Part**, **Failure Type**, and **Target** listed. Select only one box per line.

Risk Rating—use Matrix 2—the Risk matrix—to combine the **Likelihood of Failure and Impact** with the **Consequences** to determine the risk rating for each line. Write the resulting risk category in the box (*Low, Moderate, High*, or *Extreme*).

Overall tree risk rating—mark box for the highest risk determined for the tree. If more than one risk rating was determined, the overall tree risk rating is the highest of the group. Select one box.

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Section 9: Matrices, Notes, Explanations, and Descriptions

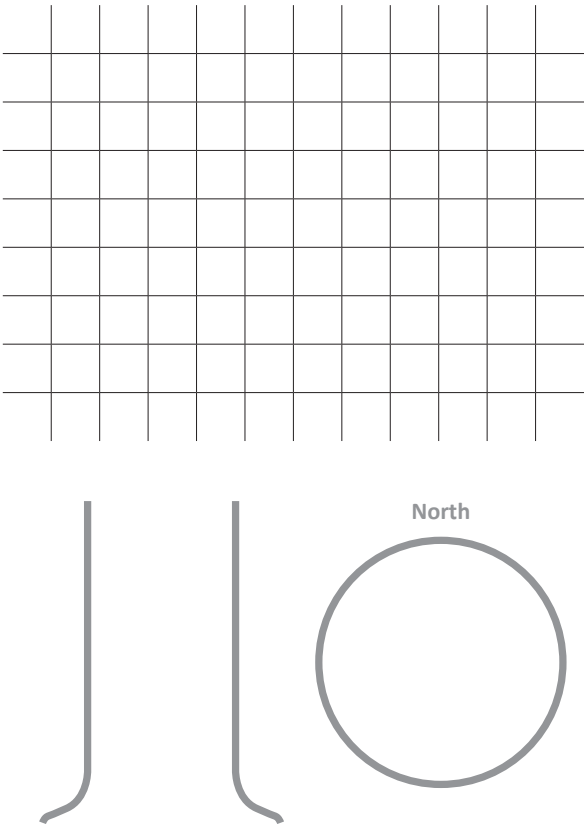
Matrix 1. **Likelihood matrix**

Likelihood of Failure	Likelihood of Impact			
	Very low	**Low**	**Medium**	**High**
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2. **Risk matrix**

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	**Minor**	**Significant**	**Severe**
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Notes, explanations, descriptions



Matrices are included to be used in determining the Likelihood of Failure and Impact (Matrix 1) and the Risk Rating (Matrix 2).

The grid, stem, and circle templates are provided for sketching any important details related to the tree or site.

The assessor may annotate the stem and circle to indicate the location of a conk, defect, or other feature on the trunk. The circle represents a cross-sectional view of the trunk from above.

Notes, explanations, descriptions—record any conditions or factors that are not well described elsewhere on the form. Include notes on anything taken into consideration for ratings or recommendations.

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Section 10: Mitigation, Inspection Limitations, Data, Advanced Assessment, and Reassessment

Option	**Mitigation** More than one failure type/target can be mitigated on each line.	**Residual Risk** of the tree
1	Mitigation option for highest risk(s)	
2		
3		

Inspection limitations: ☐ None ☐ Visibility ☐ Access ☐ Vines ☐ Root collar buried Describe: _____

Data: ☐ Final ☐ Preliminary — Advanced Assessment recommended Type/reason: _____

Reassessment recommended in _____ years/months

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Mitigation—list options to mitigate tree risk. The first line is typically used to provide a brief plan to mitigate the highest risk associated with the tree. More than one risk can be mitigated on each line. For example, "prune to remove dead branches throughout the crown and reduce the length of the overextended branch over the house by one-third."

Residual Risk of the tree—the residual risk is the risk remaining after the mitigation. Residual risk can be *none*, *low*, *moderate*, *high*, or *extreme*. It is calculated using the same procedure that was used in the initial calculation of risk. *None* should only be applied if the tree is recommended for complete removal. No space is provided at this place on the form to calculate residual risk, but it can be calculated using blank lines in the table above (Section 8) or on a separate form.

Inspection limitations—factors that limited the assessor's ability to inspect the tree. Check all that apply, describe briefly, or add other factors.

> **None**—there were no unusual obstructions to tree inspection and assessment.
>
> **Visibility**—not all parts of the tree were visible during the assessment. This includes limitations in visibility due to fog, snow, ice, rain, vegetation, infrastructure, or other factors.
>
> **Access**—not all parts of the tree were available for inspection and assessment. This includes limitations to property access, slopes, fences, or other factors.
>
> **Vines**—vegetation, such as vines, covers the soil, root collar, trunk, or branches of the tree so those parts could not be inspected and assessed.
>
> **Root collar buried**—the root collar area of the tree could not be inspected or assessed. This includes soil, mulch, pavement, decks, turf, artificial turf, and other structures that obscure the lower portion of the trunk and buttress roots.
>
> **Describe**—provide more details on the limitation, if appropriate.

Data—indicate whether sufficient information was collected to make a reasoned assessment and mitigation recommendation.

> **Final**—the assessor believes they were able to collect enough information to make a reasoned assessment of the risk of the tree and make a reasonable recommendation for mitigation and follow-up assessments.
>
> **Preliminary**—the assessor believes that additional information should be collected so they can make a reasoned assessment of the risk of the tree or to make a reasonable recommendation for mitigation or follow-up assessments.
>
> **Advanced Assessment recommended**—if the information was insufficient to make a reasoned assessment and mitigation recommendation, or a follow-up assessment is needed, indicate the "Type" of advanced assessment recommended to collect sufficient data or the "reason" for that determination. If the concern cannot be addressed by an advanced assessment, provide relevant information.

Reassessment recommended in—recommended time interval until the reassessment should take place or the reassessment frequency. Circle the appropriate unit (i.e., years, months).

This form is intended to assist with tree risk assessment data collection, analyzing risk, and making mitigation recommendations. It is not intended to be used as a final report as it lacks some of the required elements of a report as described in this *Manual*.

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Basic Tree Risk Assessment Form

Assessor _____

Client _____ Date _____

Address/Tree Location _____ Tools _____

Tree Species _____ Tree # _____ DBH _____ Height _____ **Time Frame** _____ years/months

Target #	Target Description Be specific, only one target per line.	Target Zone Check one box per target.				Occupancy Rate during time frame:			
		Drip line	1 X Ht	1.5 X Ht	>1.5 X Ht	Rare	Occasional	Frequent	Constant
1	First priority target (e.g., people near the tree)								
2	Second priority (e.g., people, structures, vehicles)								
3	Third priority (e.g., structures, vehicles)								

Site Conditions

Concerns: _____ ☐ None

Site changes: ☐ None ☐ Grade change ☐ Site clearing ☐ Changed hydrology ☐ Other _____

Crown

Foliage: ☐ None (dead) ☐ None (seasonal) Normal _____% Chlorotic _____% Necrotic _____%

Tree Health: ☐ Dead ☐ Poor ☐ Fair ☐ Good

Health concerns: _____ ☐ None

Density: ☐ Sparse ☐ Average ☐ Dense ☐ Vines/mistletoe/moss _____

Relative size crown/trunk: ☐ Small ☐ Medium ☐ Large ☐ Unbalanced ☐ Crown dieback ☐ Excessive end weight

Wind Exposure: ☐ Protected ☐ Partial ☐ Full ☐ Wind funneling Load concerns/recent changes _____

Pruning: ☐ Topped ☐ Thinned ☐ Lion tailed ☐ Raised ☐ Other _____ Live crown ratio (LCR) _____%

Branches

☐ No concerns ☐ Dead branches _____% overall Max. dia. _____

☐ Broken/hanging # _____ Max. dia. _____ ☐ Overextended

☐ Poor taper ☐ Weak attachments _____

☐ Previous branch failures _____ ☐ Similar branches present

☐ Structural support _____ ☐ Excessive sprouts ☐ Cracks

☐ Sapwood/heartwood decay ☐ Conks/mushrooms _____

☐ Cavity opening _____ ☐ Response growth _____

Main Branch and Crown Failure Types:

Failure Type 1: _____

Part size _____ Fall distance _____ Load: ☐ Low ☐ Med ☐ High

Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Failure Type 2: _____

Part size _____ Fall distance _____ Load: ☐ Low ☐ Med ☐ High

Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Trunk

☐ No concerns ☐ Codominant stems # _____ ☐ Included bark

☐ Decay ☐ Conks/mushrooms _____ ☐ Cavity opening _____

☐ Decay depth _____ ☐ Poor taper ☐ Lean ____° ☐ Corrected

☐ Dead/missing bark ☐ Cracks ☐ Ooze ☐ Lightning damage

Other _____ Response growth _____

Main Trunk Failure Type: _____

Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Root Collar, Roots, and Soil

☐ No concerns ☐ Collar buried/not visible Depth _____

☐ Stem girdling _____ ☐ Fill soil _____

☐ Significant root damage or decay ☐ Conks/mushrooms _____

☐ Cut, distance from trunk _____ ☐ Root plate lifted _____

Soil: ☐ Often saturated ☐ Limited volume ☐ Pavement/Compaction

Response growth _____

Main Root / Soil Failure Type: _____

Likelihood of Failure: ☐ Improbable ☐ Possible ☐ Probable ☐ Imminent

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

Target # _____ Protection _____

Likelihood of Impact: ☐ Very Low ☐ Low ☐ Medium ☐ High

Consequences: ☐ Negligible ☐ Minor ☐ Significant ☐ Severe

This form is for data collection and analysis. It is not intended to be used as a report.

Risk Categorization and Analysis

Tree Part Branches, Trunk, Root Collar, Roots, or Soil	**Failure Type** Dead, Hanging, Decay, Crack, etc.	**Target** Description or Number	**Likelihood of Failure**				**Likelihood of Impact**				**Failure and Impact** from Matrix 1				**Consequences**				**Risk Rating** from Matrix 2
			Improbable	Possible	Probable	Imminent	Very low	Low	Medium	High	Unlikely	Somewhat	Likely	Very likely	Negligible	Minor	Significant	Severe	

Overall tree risk rating: ☐ Low ☐ Moderate ☐ High ☐ Extreme

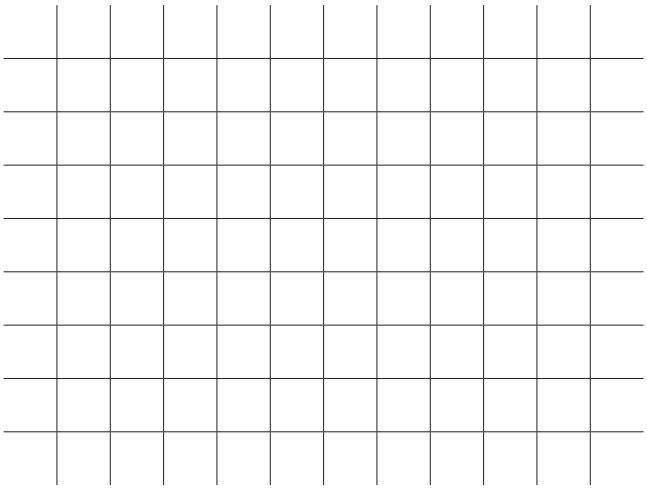
Matrix 1. **Likelihood matrix**

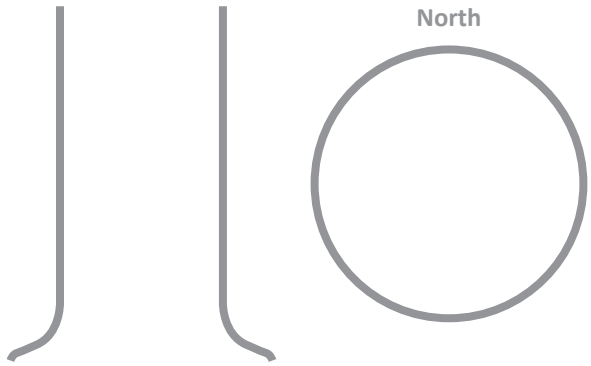
Likelihood of Failure	**Likelihood of Impact**			
	Very low	**Low**	**Medium**	**High**
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2. **Risk matrix**

Likelihood of Failure & Impact	**Consequences of Failure**			
	Negligible	**Minor**	**Significant**	**Severe**
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Notes, explanations, descriptions





Option	**Mitigation** More than one failure type/target can be mitigated on each line.	**Residual Risk** of the tree
1	Mitigation option for highest risk(s)	
2		
3		

Inspection limitations: ☐ None ☐ Visibility ☐ Access ☐ Vines ☐ Root collar buried Describe: _____

Data: ☐ Final ☐ Preliminary — Advanced Assessment recommended Type/reason: _____

Reassessment recommended in _____ years/months

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Glossary of Terms

acceptable risk—the degree of risk that is within the tolerance or threshold of the tree risk manager or controlling authority.

acceptable risk threshold—the highest level of risk that does not exceed the tree risk manager's tolerance.

advanced assessment (Level 3)—an assessment to provide information about specific tree parts, defects, targets, or site conditions, beyond what is included in a basic assessment. Specialized equipment, data collection and analysis, and expertise are usually required.

advanced decay—stage of wood decay in which the decay is obvious in the wood and major mechanical strength loss has occurred.

adventitious branch—branch arising from a stem or parent branch and having no connection to apical meristems.

adventitious root—roots arising from roots or stems and having no connection to apical meristems.

aerial assessment—assessment of parts of a tree not visible from the ground, including the trunk, stems, and branches; aerial assessments may include evaluation of internal decay.

aerial patrol—overflights of a utility right-of-way, large areas, or individual trees to record the location of trees that are likely to fail and cause harm.

analysis—detailed examination of the elements or structure of something.

angiosperm—plant with seeds borne in an ovary. Consists of two large groups: monocotyledons (grasses, palms, and related plants) and dicotyledons (most woody trees, shrubs, herbaceous plants, and related plants)(contrast with *gymnosperm*).

annual rings—rings of xylem that are visible in a cross section of the stem, branches, and roots of some trees. In temperate zones, the rings typically represent one year of growth.

arborist—an individual engaged in the profession of arboriculture who, through experience, education, and related training, possesses the competence to provide for or supervise the management of trees and other woody plants.

aspect—the direction that a slope faces usually expressed as a cardinal direction (e.g., north facing).

barrier zone—a chemical and anatomical barrier formed by the cambium present at the time of wounding in response to wounding. Inhibits the spread of decay into xylem tissue formed after the time of wounding. Wall 4 in the CODIT model (contrast with *reaction zone*).

basal swelling—increased wood growth in the area near or where the trunk and roots come together.

basic assessment (Level 2)—a ground-based, visual assessment of a tree and surrounding site and a synthesis of the information collected. It requires that a tree risk assessor inspect completely around the accessible tree trunk looking at the visible aboveground roots, trunk, branches, and site. It may include the use of simple tools.

Beaufort scale—a means of categorizing wind speed on a scale of 1 to 12.

bending moment—the load that results from a force acting on a lever, causing a structure or member of the structure to bend; it is calculated by multiplying the force that acts perpendicular to the lever by the length of the lever (see *moment*).

biomechanics [tree biomechanics]—the study of the action of forces on living trees.

bow—leans characterized by the top of the tree bending over more than the lower trunk, creating a curve.

brace rod (rigid brace)—metal rod used to support weak sections or crotches of a tree.

bracket—the fruiting body of a decay fungus (see *conk*).

breach of duty (of care)—failure to take reasonable care to avoid injury or damage to a person or property in a situation where the law imposes a duty of care.

brown rot—fungal wood rot characterized by the breakdown of cellulose (contrast with *soft rot* and *white rot*).

buckling—failure mode characteristic of collapsing under compressive stress.

bulge—swellings on branches, trunks, or root flares; often caused by new tissue formed as a response to movement and that reinforces the wood structure at the weak area.

buttress root—roots at the trunk base that help support the tree and equalize mechanical stress.

butt rot—decay of the lower trunk, trunk flare, or buttress roots.

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cabling (flexible bracing)—installation of steel or synthetic cable in a tree to provide supplemental support to weak branches or branch unions.

callus—undifferentiated tissue formed by the cambium, usually as the result of wounding (contrast with *woundwood*).

cambium—thin layer(s) of meristematic cells that give rise (outward) to the phloem and (inward) to the xylem, increasing stem and root diameter.

canker—localized, diseased, usually necrotic area on stems, roots, and branches. Often shrunken and discolored.

cavity—open or closed hollow within a tree stem, branch, or root, usually associated with decay.

cellulose—complex carbohydrate found in the cellular walls of the majority of plants, algae, and certain fungi.

center of force—the point toward or from which a force acts; the resultant point of aggregate forces.

center of gravity—the point on an object where its weight is evenly balanced in all directions.

center of pressure [mechanics]—the point on an object that can represent the average effect of varying pressures.

client—the person or organization for whom professional services are rendered. The client in tree risk assessment is usually the tree risk manager.

clinometer—instrument used for measuring the height of a tree or other structure.

CODIT—acronym for Compartmentalization of Decay in Trees. Acronym may also be used to stand for Compartmentalization of Discoloration in Trees or Compartmentalization of Disfunction in Trees (see *compartmentalization*).

codominant [trees in a stand]—more than one tree sharing dominance in a stand of trees.

codominant stem—forked branches nearly the same diameter, arising from a common junction and lacking a normal branch collar.

column of decay—wood decay inside a tree that extends longitudinally up and down a stem or through a branch.

compartmentalization—natural defense process in trees by which chemical and physical boundaries are created that act to limit the spread of disease and decay organisms (see *CODIT*).

compression—in mechanics, the action of forces to squeeze, crush, or push together any material or substance (contrast with *tension*).

compression crack—fracture caused by compressive stress.

compression wood—reaction wood in gymnosperms, and some angiosperms, that develops on the underside of branches or leaning trunks and is important in load bearing (contrast with *tension wood*).

conclusions—the summary and results of a risk assessment.

conflicts [tree conflicts]—trees or tree parts that interfere with people, property, or activities.

conk—fruiting body or nonfruiting body (sterile conk) of a fungus. Often associated with decay (see *bracket*).

consequences—effects or outcome of an event. In tree risk assessment, consequences of failure and impact include personal injury, property damage, or disruption of activities. Categories are *negligible, minor, significant,* and *severe*.

consequences of failure—personal injury, property damage, or disruption of activities. Categories are *negligible, minor, significant,* and *severe*.

constant [occupancy]—a target is present at nearly all times, 24 hours a day, 7 days a week.

context—in tree risk assessment, the parameters of the risk assessment, including objectives, how risk will be evaluated, communication flow, applicable policies or legal requirements, and limitations of the risk assessment.

controlling authority—official group or agency that regulates or administers tree planting, pruning, removal, and/or management.

corrected lean—tree lean characterized by a leaning lower trunk and a top that is more upright as a result of self-correction; sweep.

crack—separation of wood fibers.

damping—the process through which the swaying motion of a tree or tree part(s) dissipates wind energy.

decay—process of degradation by microorganisms. See *wood decay*.

decay–detection device—an instrument or tool developed to detect decay in tree parts.

decomposition—the breakdown or separation of a substance into simpler substances.

defect—imperfection, weakness, or lack of something necessary. In trees, defects are injuries, growth patterns, decay, or other conditions that that may predispose a tree to failure.

definite indicator—an indicator that decay is definitely present.

degree of harm—the amount or extent of injury, damage, or disruption.

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diameter—the length of a straight line through the center of a circle.

diameter tape—a measuring tape scaled such that when it encircles a tree trunk, the diameter can be read directly.

discoloration—wood response of a tree to microorganisms, including bacteria and non-decay-causing fungi, resulting in dead, darkened wood with little strength.

disruption—a delay or interruption of progress or continuity.

dominant [trees in a stand]—the tree or trees in a stand that are typically larger in height (taller), diameter, and crown spread than all the adjacent trees.

drag—wind resistance.

drip line—imaginary line defined by the branch spread of a single plant or group of plants.

drive-by [assessment]—limited visual inspection of one side of the tree, performed from a moving vehicle that is appropriate to the site and scope of work; may also be called a "windshield assessment."

duty of care—legal obligation that requires an individual to apply reasonable actions when performing tasks that may potentially harm others.

dynamic—study of how objects move under the action of forces.

earlywood—portion of an annual ring (growth ring) that forms during spring, characterized by large-diameter cells and thin walls. Also called springwood (contrast with *latewood*).

edge tree—a tree on the edge of a stand, growing under conditions of light and exposure different from those prevailing within the stand.

epicormic shoot— shoot arising from a dormant bud or from newly formed adventitious tissue.

ethics—the body of moral principles or values governing a group or individual's conduct.

event—occurrence of a particular set of circumstances. In tree risk assessment there are two general types of events: (1) a tree failure impacting a target and (2) a tree conflicting with activities.

extreme [risk rating]—defined by its placement in the risk rating matrix (Matrix 2); failure is *imminent* with a *high* likelihood of impacting the target, and the consequences of the failure are *severe*.

failure [tree failure]—the breakage of a tree or its parts (stem, branches, fruit, or roots) or the loss of mechanical support in the soil-root system.

failure type—the manner in which a tree or tree part could fail (e.g., dead, hanging, decayed, cracked).

fiber—elongated, tapering, thick-walled cell that provides strength to wood.

fissure—a long, narrow opening or split.

flexure wood—response growth triggered by the continued flexing of a tree stem or branch.

force—any action or influence causing an object to accelerate/decelerate. Calculated as mass multiplied by acceleration. Is a vector quantity.

forest stand—a group of trees in a wooded setting.

freeze-thaw crack—frost crack; vertical split in the wood of a tree, often near the base of the bole, caused by internal stresses and low temperatures.

frequency [biomechanics]—the number of occurrences per unit of time (e.g., sway of a tree in the wind).

frequent [occupancy]—the target zone is occupied for a large portion of the day or week.

friction—specific type of force that resists the relative motion between two objects in contact. The direction is always opposite the motion.

frost crack—vertical split in the wood of a tree, often near the base of the trunk, caused by internal stresses and low temperatures.

fungal fruiting structures—the reproductive structures of a fungus (conks, brackets, mushrooms).

fungus (pl. fungi)—group of organisms from the kingdom Fungi, including yeasts, molds, mushrooms, and smuts. Typically multicellular, saprophytic, or parasitic and lacking vascular tissue and chlorophyll. Reproduces vegetatively and by various types of spores borne in fruiting bodies.

girdling root—root that encircles all or part of the tree trunk or the tree's other roots, constricting the vascular tissue and inhibiting secondary growth and the movement of water and photosynthates.

grade changes—a topographic alteration to the surface of the ground.

gravity—the force that attracts a body toward the center of the earth.

ground-penetrating radar (GPR)—a nondestructive device that uses radar pulses to image the subsurface.

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guy—(1) a steel or synthetic-fiber cable between a tree or branch and an external anchor (another tree, the ground, or other fixed object) to provide supplemental support; (2) a steel cable between a utility pole and an external anchor (another pole, the ground, or other fixed object, which may sometimes be a tree) to keep the pole upright. Guys act in tension (contrast with *prop*).

gymnosperm—plants with exposed seeds, usually within cones (contrast with *angiosperm*).

hand pull test—a load test that involves installing a line in a tree and then pulling and releasing the line several times to move the tree or branch. Most commonly used in a prework inspection but can be used as part of an advanced tree risk assessment.

harm—personal injury or death, property damage, or disruption of activities.

hazard—situation or condition that is likely to lead to a loss, personal injury, property damage, or disruption of activities; a likely source of harm. In the context of trees, a hazard is a tree or tree part(s) identified as a likely source of harm.

hazard tree—a tree identified as a likely source of harm. Also called "hazardous tree."

heartwood—wood that is altered (inward) from sapwood and provides chemical defense against decay-causing organisms and continues to provide structural strength to the trunk. Trees may or may not have heartwood (contrast with *sapwood*).

heartwood rot—any of several types of fungal decay of tree heartwood, often beginning with infected wounds in the living portions of wood tissue. Also called heart rot.

hemicellulose—any of a group of plant polysaccharides that form a matrix with cellulose and lignin or pectin in plant cell walls.

high [likelihood of impact]—the failed tree or tree part is likely to impact the target. This is the case when there is a constant target, with no protection factors, and the direction of fall is toward the target.

high [risk rating]—defined by its placement in the risk rating matrix (Matrix 2); consequences are *significant* and likelihood is *very likely* or *likely*, or consequences are *severe* and likelihood is *likely*.

history of failure—evidence of past tree failure within a tree or on a site.

hydrology—study of the properties, distribution, and effects of water on the Earth's surface, underground, and in the atmosphere.

imminent [likelihood of failure]—failure has begun or will occur soon in normal weather or with minimal additional loading.

impact—(*v.*) striking a target or causing a disruption that affects activities.

improbable [likelihood of failure]—failure is not likely in normal or severe weather within the specified time frame.

incipient decay—wood decay that is at a stage that is not yet visible.

included bark—bark that becomes embedded in the union between branch and trunk or between codominant stems. Causes a weak structure.

inspection—a visual observation of tree health, structure, and/or form.

interior tree—a tree within a stand of trees, protected from wind exposure.

intermediate decay—wood decay may appear as discoloration and there may be textural differences.

known target—target(s) that are visible to the tree risk assessor, and those described by the tree risk manager.

land disturbances—disruptions to a terrestrial site, community, or ecosystem that alters the physical environment.

land-use history—actions, events, or changes that have taken place on a site.

latewood—portion of an annual ring (growth ring) that forms during summer, characterized by small-diameter cells with thick walls. Summer wood (contrast with *earlywood*).

lean—predominant angle of the trunk from vertical.

legal precedent—a principle or rule established by a prior court or other decision-making body.

level(s) of assessment—categorization of the breadth and depth of inspection and analysis used in an assessment; Level 1, 2, or 3.

lever (lever arm)—the distance between the center of an applied force and the point where the object will bend or rotate.

liability—something for which one is responsible. Legal responsibility.

LiDAR (Light Detection and Ranging)—a remote sensing method that uses laser technology to measure tree size and location in relation to the target of concern.

lightning protection system—hardware installed in a tree to conduct the charge of a lightning strike to ground.

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lignin—organic substance that impregnates certain cell walls to thicken and strengthen the cell to reduce susceptibility to decay and pest damage.

likelihood—the chance of an event occurring. In the context of tree failure, the term may be used to specify: (1) the chance of a tree failure occurring; (2) the chance of impacting a specified target; and (3) the combination of the chances of a tree failing and impacting a specified target.

likelihood matrix—a tool for categorizing the combined likelihood of a failure impacting a target.

likelihood of failure—the chance of a tree failure occurring within the specified time frame. Categories are *improbable*, *possible*, *probable*, and *imminent*.

likelihood of failure and impact—the chance of a tree failure occurring and impacting a target within the specified time frame. Categories are *unlikely, somewhat likely, likely,* and *very likely.*

likelihood of impact—the chance of a tree failure impacting a target during the specified time frame. Categories are *very low*, *low*, *medium*, and *high*.

likely [likelihood of failure and impact]—defined by its placement in the likelihood matrix (Matrix 1); *imminent* likelihood of failure and *medium* likelihood of impact, or *probable* likelihood of failure and *high* likelihood of impact.

limitations [tree risk assessment]—factors that limit the precision, applicability, or extent of a tree risk assessment.

limited visual assessment (Level 1)—a visual assessment from a specified perspective of an individual tree or a population of trees near specified targets to identify specified conditions or obvious defects.

live crown ratio (LCR)—the ratio of crown length to total tree height.

load—(1) a general term used to indicate a force, bending moment, torque, or pressure applied to a structure, structural member, or material; (2) any force or moment that acts on a structure.

load-bearing capacity—the capacity of a structural member or material to carry a load before failure occurs.

load testing—in advanced tree risk assessment, pulling tests to measure or observe the amount of inclination and/or deformation to assess stability.

low [likelihood of impact]—there is a slight chance that the failed tree or tree part will impact the target.

low [risk rating]—defined by its placement in the risk rating matrix (Matrix 2); consequences are *negligible* and likelihood is *unlikely*, or consequences are *minor* and likelihood is *somewhat likely*.

mallet—a broad-headed hammer made of wood, plastic, or resin used for sounding a tree.

mass damping—a process by which the amplitude of oscillations is reduced; in trees, motion created by the forces of wind or rigging operations may be reduced through branch movement.

matrix—a rectangular array of rows and columns used to facilitate problem solving or decision making.

mechanical stress—a measure of the internal forces acting within a deformable body; force per unit area.

mechanics—study of forces and their effects on bodies at rest or in motion.

medium [likelihood of impact]—the failed tree or tree part could impact the target but is not expected to do so.

meristematic tissue—undifferentiated tissue in which active cell division takes place. Found in the root tips, buds, cambium, cork cambium, and latent buds.

minor [consequences]—minor personal injury, low- to moderate-value property damage, or small disruption of activities.

mitigation—in tree risk management, the process for reducing risk.

mitigation options—alternatives for reducing risk.

mitigation priority—established hierarchy for mitigation of risks based on risk ratings, budget, resources, and policies.

mobile target—a target that is in motion or intermittently moving.

moderate [risk rating]—defined by its placement in the risk rating matrix (Matrix 2); consequences are *minor* and likelihood is *very likely* or *likely*, or likelihood is *somewhat likely* and consequences are *significant* or *severe*.

moment—a turning, bending, or twisting force exerted by a lever, defined as the force (acting perpendicular to the lever) multiplied by the length of the lever.

movable target—target that can be relocated.

multiple risks—the concept that any tree, part, or failure mode could represent more than one type of risk.

multiplicative factors—conditions that may increase the size of the target zone and the likelihood of impact.

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negligence—failure to use reasonable care, resulting in damage or injury to another.

negligible [consequences]—no personal injury, low-value property damage that can be replaced or repaired, or short-term disruption of activities.

neutral plane—an imaginary plane where there is neither tension nor compression.

occasional [occupancy]—the target zone is occupied by people or other targets infrequently or irregularly.

occupancy rate—the amount of time a target is within a target zone within the time frame specified for the risk assessment. Categories are *constant*, *frequent*, *occasional*, and *rare*.

oozing—seeping or exudation from a tree cavity or other opening.

open grown—a tree that has grown with exposure to wind and other elements from all directions.

overextended branch—branch that extends outside the normal crown area.

parenchyma—thin-walled, living cells essential in photosynthesis, radial transport, energy storage, and production of protective compounds.

pathogen—causal agent of disease. Usually refers to microorganisms.

patterns of failure—common modes of tree failure within a tree species or failure of multiple trees in a contiguous area that share similar site histories or environmental conditions.

phloem—plant vascular tissue that transports photosynthates and growth regulators. Situated on the inside of the bark, just outside the cambium. Is bidirectional (transports up and down)(contrast with *xylem*).

possible [likelihood of failure]—failure is not likely in normal weather but may occur in severe weather within the specified time frame.

potential indicator—an indicator that decay might be present.

precipitation—any form of water that falls to the Earth's surface, such as rain, snow, or sleet.

prioritizing targets—a process for ranking targets according to importance or value.

probability—the measure of the chance of occurrence expressed as a number between 0 and 1 (0 to 100 percent), where 0 is impossibility and 1 is absolute certainty. Often expressed as a percentage.

probable [likelihood of failure]—failure may occur in normal weather and is expected to occur in severe weather within the specified time frame.

probe—a stiff, small-diameter rod, stick, or wire that is inserted into a cavity or crack to estimate its size or depth.

prop—rigid brace, acting in compression, to support a tree, tree branch, or utility pole. Prop pole (contrast with *guy*).

protection factors—structures, trees, or other features that block, deflect, or slow down a falling object.

pruning—removing branches (or occasionally roots) from a tree or other plant, using approved practices, to achieve a specified objective.

pruning cycle—in utility and municipal arboriculture, the time scheduled between pruning events that is established as a guideline for providing reasonable clearance between trees and other objects or infrastructure.

qualitative risk assessment—a process that uses ratings of consequences and likelihood to categorize risk.

quantitative risk assessment—a formal and systematic method using measurable, objective data to calculate a numeric value for risk, usually based on probability of an event and costs of the consequences.

radius—distance from the center to the perimeter of a circle. One half of diameter.

ram's horn—inward curling formation of woundwood resembling the horns of a ram.

rare [occupancy]—the target zone is not commonly used by people or other mobile/movable targets.

rays—parenchyma tissues that extend radially across the xylem and phloem of a tree and function in transport, storage, structural strength, and defense.

reaction wood—wood formed in leaning or crooked stems, or on upper or lower sides of branches, as a means of counteracting the effects of gravity (see *compression wood* and *tension wood*).

reaction zone—natural boundary formed chemically within a tree to separate damaged wood from existing healthy wood. Important in the process of compartmentalization (contrast with *barrier zone*).

reassessment interval—recommendation for the next tree risk assessment or the number of tree risk assessments per given unit of time (e.g., once every three years).

recommendations—one or many alternatives that are promoted to achieve a desired outcome, based on professional judgment.

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reconfigure—to alter the form or layout of something.

remote sensing—the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance. In tree risk assessment, technologies that provide the position of trees relative to potential targets and conflicts (e.g., streets, structures, power lines) such as Light Detection and Ranging (LiDAR) and Google Street View images.

reporting [risk assessment]—presenting the client with a summary statement describing the results of a tree risk assessment.

residual risk—risk remaining after mitigation.

residual risk rating—the risk rating after mitigation treatments have been applied.

resistance-recording drill—a device consisting of a specialized micro-drill bit that drills into trees and graphs resistance to penetration; used to detect internal differences in the wood, such as decay.

response growth —new wood produced in response to loads to compensate for greater strain in marginal fibers; includes reaction wood (compression and tension), flexure wood, and woundwood. Also called "adaptive growth."

retain and reassess—the recommendation to keep a tree and conduct follow-up assessments after a stated reassessment interval.

retrenchment—natural process during which an overly mature tree reduces its crown and increases its girth to consolidate resources and increase longevity; the deliberate process of reducing tree height to mimic natural processes.

rhizomorph—a root-like aggregation of fungal hyphae.

rib—longitudinal bulge of response wood growth.

ridge—series of raised strips, usually with a transverse orientation on the stem.

risk—in this manual, the combination of the likelihood of an event (i.e., tree failure and impact) and the severity of the consequences (adapted from ISO Guide 73:2009).

risk aggregation—the consideration of multiple risks in combination.

risk analysis—the systematic use of information to identify sources and to estimate the risk.

risk assessment—a systematic process of risk identification and analysis.

risk categorization—the process of assigning risk and risk factors to categories based on severity or hierarchy.

risk evaluation—the process of comparing the assessed risk against given risk criteria to determine the significance of the risk.

risk management—the application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate risk.

risk matrix—a tool for ranking and displaying risks by assigning ratings for consequences and likelihood.

risk mitigation—actions taken to reduce risk.

risk perception—the subjective perceived level of risk from a situation or object, often differing from the actual level of risk

risk rating—a categorization of risk based on the combination of the likelihood of failure and impact and its potential consequences. Categories are *low*, *moderate*, *high*, and *extreme*.

risk tolerance—degree of risk that is acceptable to the owner, manager, or controlling authority.

root collar excavation (RCX)—process of removing soil to expose and assess the root collar (root crown) of a tree.

root rot—decay located in the roots.

saprophyte—organism that lives on and may act to decay dead organic matter.

sapwood—outer wood (xylem) that is active in longitudinal transport of water and minerals.

sapwood decay—decay located in the sapwood. A usual sign of this classification of rot is numerous, small fruiting bodies along the bark's surface.

scope of work—the defined project objectives and requirements; a description of the specific work to be performed for specific trees, schedule, and reporting method(s).

seam—lines formed where two edges of bark meet at a crack or wound.

secondary xylem—xylem produced to the interior of the vascular cambium during secondary growth.

severe [consequences]—serious personal injury or death, high-value property damage, or major disruption of important activities.

shear—(1) *n*. in mechanics, the movement or failure of materials, especially laminar material such as wood, by sliding side by side; (2) *n*. a tool used to cut small-diameter plant material, including secateurs and snips, as well as long-bladed hand tools and power tools used to cut hedges; (3) *v*. to cut; often used to describe cutting foliage or stems to a single plane, as in a hedge.

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shear plane crack—a crack at the neutral plane between tension and compression stresses.

shell wall—the remaining solid wood around a cavity or internal wood decay.

should—an advisory recommendation. This document does not attempt to distinguish between "should" and "shall" as is done in most standards.

significant [consequences]—substantial personal injury, moderate- to high-value property damage, or considerable disruption of activities.

site modification—as pertains to risk mitigation, actions take to improve tree health and/or encourage root growth to facilitate a tree's natural response growth to reduce the likelihood of failure.

soft rot—decay of plant tissues characterized by the breakdown of tissues within the cell walls (contrast with *brown rot* and *white rot*).

soil compaction—compression of the soil, often as a result of vehicle or heavy-equipment traffic, that breaks down soil aggregates and reduces soil volume and total pore space, especially macropore space.

soil depth—the vertical extent of plant-usable soil present below ground.

somewhat likely [likelihood of failure and impact]—defined by its placement in the likelihood matrix (Matrix 1); *imminent* likelihood of failure and *low* likelihood of impact, or *probable* likelihood of failure and *medium* likelihood of impact, or *possible* likelihood of failure and *high* likelihood of impact.

sonic assessment—a process of measuring wood density, or other mechanical properties, using an instrument that transmits, receives, and records the velocity of sound waves through wood.

sounding—process of striking a tree with a mallet or other appropriate tool and listening for tones that indicate dead bark, a thin layer of wood outside a cavity, or cracks in wood.

standard of care—degree of care that a reasonable person should exercise in performing duty of care; a measurement used to assess whether an individual acted in a reasonable manner.

static load—constant load exerted by a mass due to its weight.

static pull test—in advanced tree risk assessment, a load test that measures outermost fiber strain in the stem or branches, and/or inclination at the root flare, in response to a controlled pull.

static target—target that cannot be easily relocated.

strain—the deformation resulting from a stress, measured as a change in specimen length per unit of total length.

stratifying targets—a process for classifying targets according to importance or value.

strength loss—degradation of the ability to withstand mechanical stress.

stress—(1) in Plant Health Care, a factor that negatively affects the health of a plant; a factor that stimulates a response; (2) in mechanics, a force per unit area.

stress raisers—an area of increased stress such as a sharp bend or where a canker is present.

structural defect—feature, condition, or deformity of a tree that indicates a weak structure or instability that could contribute to tree failure.

structural support system—a device or mechanism providing supplemental support to individual branches and/or entire trees.

subdominant [trees in a stand]—understory trees in a stand or forest with growth somewhat restricted by larger nearby trees.

suberin—a waxy substance present in some cell walls.

subjectivity—bias introduced due to personal feelings, opinions, knowledge, or experiences.

sudden branch drop (SBD)—the sudden, unanticipated failure of a tree branch during calm conditions and warm temperatures. It is often associated with long, horizontal branches with little or no discernable defect. Also known as "summer branch drop."

suppressed [trees in a stand]—understory trees in a stand or forest with growth severely restricted by competing nearby trees.

sweep—corrected tree lean characterized by a leaning lower trunk and a top that has grown back toward vertical.

taper—change in diameter over the length of trunks, branches, and roots.

target (risk target)—people that could be injured, property that could be damaged, or activities that could be disrupted by a tree failure.

> **known target**—target(s) that are visible to the tree risk assessor, and those described by the tree risk manager.
>
> **mobile target**—target that is in motion or intermittently moving.
>
> **moveable target**—target that can be relocated or moved.

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static target—target that is fixed or not readily moved.

target aggregation—combining two or more targets when rating the likelihood of impact.

target-based mitigation—action focused on the target; risk mitigation actions are aimed at reducing the likelihood of impact or the consequences but do not change the likelihood of failure.

target management—acting to control the exposure of targets to risk.

target value—the monetary worth of something; the importance or preciousness of something.

target zone—the area where a tree or tree part is likely to land if it were to fail.

tension—in mechanics, the action of forces to stretch or pull apart any material or substance (contrast with *compression*).

tension wood—a form of reaction wood in angiosperms that forms on the upper side of branches or the trunks of leaning trees (contrast with *compression wood*).

time frame—the period for which an assessment is defined.

timeline—time period for recommended mitigation.

tomography—use of multiple sensors placed around a trunk or branch to record sound or magnetic waves traveling through the wood, with measurements resulting in a picture of internal density characteristics. Typically used in arboriculture to measure the extent of decay in trees.

topography—the land and water features of an area, including changes in elevation.

torsion—the action of twisting or being twisted.

tracheid—elongated, tapering xylem cell adapted for the support and transport of water and elements.

transverse crack—cracks that run across the wood grain (horizontally on a vertical stem).

tree—as used in this manual, all parts of the tree, including branches, trunk, and root system.

tree architecture—the structural form and shape of a tree.

tree-based mitigation—action performed on the tree; risk mitigation actions are typically aimed at reducing the likelihood of tree failure but may also reduce the likelihood of impact or consequences.

tree conflict—an interference between the needs of a tree and society or infrastructure.

tree failure—the breakage of stems, branches, or roots, or the loss of mechanical support in the soil-root system. Unless specifically stated otherwise, in this Manual, "tree failure" means failure of the whole tree, branch, roots, or other parts.

tree growth regulator—chemical that can be applied to trees that slows terminal growth by reducing cell elongation.

tree inspection—a visual observation of tree health, structure, and/or form to provide information to the tree owner or manager to guide tree health care or management decisions. While tree inspection is a component of a tree risk assessment, tree inspection can be conducted to achieve many objectives.

tree risk assessment—a systematic process used to identify, analyze, and communicate tree risk.

tree risk assessor—an arborist with specialized education, training, skills, experience, and competency to conduct tree risk assessments.

tree risk evaluation—the process of comparing the assessed risk with risk criteria to determine if the risk is acceptable.

tree risk management—the application of policies, procedures, and practices used to identify, analyze, communicate, evaluate, mitigate, and reassess tree risk.

tree risk manager—the person responsible for tree management or the controlling authority that regulates tree management. Examples include clients, property owners, homeowners, municipalities, and utilities.

tree risk rating—the combination of likelihood of failure and impact with consequences of failure. Categories are *extreme*, *high*, *moderate*, and *low*

tree species failure profile—recurring patterns of failure observed in a tree species.

unacceptable risk—a degree of risk that exceeds the tolerance of the tree risk manager (e.g., owner, manager, controlling authority).

tree population—a defined set, group, or collection of trees.

uncertainty—lack of sureness, due to imperfect or unknown information.

unlikely [likelihood of failure and impact]—defined by its placement in the likelihood matrix (Matrix 1); *possible* or *probable* likelihood of failure and *low* likelihood of impact, or *possible* likelihood of failure and *medium* likelihood of impact, or *improbable* likelihood of failure with any likelihood of impact rating, or any likelihood of failure rating with *very low* likelihood of impact.

vascular cambium—lateral meristem from which secondary xylem and secondary phloem originate (see *cambium*).

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verbal report—oral report; results of the risk assessment delivered to the client orally.

very likely [likelihood of failure and impact]—defined by its placement in the likelihood matrix (Matrix 1); *imminent* likelihood of failure and *high* likelihood of impact.

very low [likelihood of impact]—the chance of the failed tree or tree part impacting the specified target is remote.

vessel—end-to-end, tube-like, water-conducting cells in the xylem of angiosperms.

veteran tree—a tree which, because of its great age, size, or condition, is of exceptional cultural, landscape, or nature conservation value.

visual assessment—method of assessing the structural integrity of trees using external symptoms of mechanical stress (such as bulges, reactive growth, etc.) and defects (cracks, cavities, etc.).

walk-by [assessment]—a limited visual assessment of one or more sides of the tree, performed by the tree risk assessor from a sidewalk or footpath.

weather categories

> **normal weather**—weather based on a location's average temperature, wind speed, and precipitation for the previous 30 years.
>
> **severe weather**—weather that has the potential to cause damage, including strong winds and storms.
>
> **extreme weather**—severe weather that is historically infrequent for the region and has the potential to cause devastating damage. Extreme events include blizzards, tornadoes, heavy accumulations of rain, snow, or ice, and tropical cyclones (hurricanes and typhoons).

white rot—fungal decay of wood in which both cellulose and lignin are broken down (contrast with *brown rot* and *soft rot*).

wildlife habitat—an environment suitable for sustaining one or more species of animals.

wind exposure—exposure to the forces of wind.

wind load—the force on a tree or structure resulting from the impact of wind.

windthrow—uprooting and overthrowing of a tree caused by wind.

wind velocity—the speed of wind.

wood decay—the process of wood degradation by microorganisms.

work order—a written document detailing the work to be completed and authorizing performance of contracted work.

woundwood—lignified, differentiated tissues produced on woody plants as a response to wounding.

written report—a document delivered in print or electronic format, containing the results of a tree risk assessment.

xylem—main water- and mineral-conducting tissue in trees and other plants. Provides structural support (contrast with phloem).

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Index

Locators in **bold** indicate Figures. Locators in *italics* indicate Tables.

A

abnormal root flares/fused buttress roots, 154
acceptable risk, 161, 168–169
advanced decay, 105
adventitious branches, 136
adventitious roots, 154, **155**
aerial assessment (crown assessment), 33, **35**
aerial patrol, 26
angiosperms, 87
ANSI A300 standard for risk assessment, 23
arborist, 5, 7, 16, 121, 182
Armillaria infection, 103, 104, 108, **111**, 154
"as low as reasonably practicable" (ALARP), 183
aspect, 79

B

barrier zone, 102
basal rots, 108–109
basal swelling, 109
basal trunk decay, 154
basic assessment (Level 2) report, 192
Beaufort scale, 73, 75
bending moment, 117, 118
binoculars, 30, 33
biomechanics, 117
black peppermint eucalyptus *(Eucalyptus amygdalina),* 124
blue gum eucalyptus *(Eucalyptus globulus),* 156
bows, 151–152
brace rods (rigid braces), 177
brackets, 102
branch defects and conditions, 135–139
breach of duty of care, 13
brown rots, 102, 104
bulges, 141–142
buried root collar, 154
buttress roots, 95

C

cables (flexible braces), 177
cambium, 91
canker rot fungi, 103
cankers, 133, 141
carpenter ants, 112
case studies
  assessing the extent of internal decay, 128–129
  assessment of a shear plane crack, 145
  holding factors constant in a level 1 assessment, 28–29
  influence of site factors, 86–87
  interpreting observations, 97–98
  need for an advanced assessment, 124–125
  need for tree risk assessment, 9
  occupancy rate and likelihood of impact, 58–59
  providing mitigation options, 185–186
  reporting, 196–198
  scope of work, 14–15
  sounding and probing to assess decay, 113–114
  tree lean and likelihood of failure, 150–151
  using the matrices, 170–171
cavities, 107, 140–141
cell phone apps, 30
cellulose, 91
center of gravity, 118
center of pressure, 118
clinometer, 30
coast live oak *(Quercus agrifolia),* 155
CODIT (Compartmentalization of Decay in Trees), 105–108, 109, 140
  Wall, 35, 36, 40, 102
codominant stems, 133, 136–137

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codominant trees, 78
column of decay, 107
compartmentalization, 102, 105
compass, 31
compression, 117, 119
compression wood, 91, 94
Coniferiporia, 103
conks (brackets), 102
consequences of failure, 9–10, 45, 52–53, **53**, 161, 164
categorizing, 63, 65
constant occupancy, 50
context, defined, 9
contract for assessment work, 15
corrected leans (sweeps), 151
cracks, 133, 143–152
crown dieback, thinning, or decline, 155
cubical brown rot, 104

D

damping, 126
dead or detached bark, 154
dead or dying parts, 135
decay, 102
testing, 33, 35–36
decay fungi, 139–140
CODIT, 105–109
indicators of decay, 110–112
location in the tree, 108–110
progression of decay, 104–105
types of, 102–104
deciduous tree, 129
decomposition, 105
defects and response growth, 133–134
branch defects and conditions, 135–139
cracks, 143–144, 146–148
dead or dying parts, 135
fire-damaged trees, 135
and the likelihood of failure, 134–135
live crown ratio, taper, and height/diameter ratio, 152–153
root problems, 153–155
tree architecture, 148–149, 151–152
tree species failure profiles, 155–156
trunk defects and conditions, 139–142
definite indicators of decay, 110–111, 140
diameter tape, 30
diffuse porous, 92
digging tools, 30–31
direction of fall, 52, 53–54
discoloration, 105
disruption of activities, 45
dominant trees, 78
drag, 117–118
drilling, 35–36
drive-by, 26
duty of care, 13
dynamic force, 118

E

earlywood, 92
edge trees, 77
elms (*Ulmus* spp.), 185
epicormic shoots, 136
ethics, 13
exposure, effect on tree growth, 77–78
extreme weather, 74

F

fibers, 91
fire-damaged trees, 135
flexure wood, 91, 95
force, 117
forest stand, 83
freeze–thaw cracks, 148
frequency, 126
frequent occupancy, 50
friction, 119
frost cracks, 148
fungal fruiting structures, 111, 153

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G

Ganoderma sp., 104, **111**
genetic testing, 36
girdling roots, 133
Google Earth™, 85
Google Maps™, 85
Google Street View, 26
grade changes, 73, 81, 84–85
ground penetrating radar (GPR), 40
growth rings, 92
guys, 177
gymnosperms, 91

H

hand pull test, 37
harm, 7
hazard tree assessment, 7
heartwood, 92, 103
heartwood decay, 13, 123, 134
heartwood rot (heart rot), 109–110
Heterobasidion irregulare, 103
historical weather data, 34, 41
history of failure, 73, 74

I

incipient decay, 105
included bark, 133, 137
increment borer, 35–36
interior trees, 83–84
intermediate decay, 105
irrigation, 81

K

known target, 45
  defined, 47
Kretzschmaria deusta (Ustulina deusta), 104

L

Laetiporus sp., 104, **111**
Larix, 108
latewood, 92
Lawson cypress *(Chamaecyparis lawsoniana),* 150
lean, 149, 151
legal counsel, **5**
legal precedents, 13
lever, 118
  arm, 123
LiDAR (light detection and ranging), 26
lightning protection systems, installing, 178–179
lignin, 91
likelihood matrix (matrix 1), 161, 164
likelihood of failure, 29, 45, **53**, 56, 59, 113–114
  applying mechanical principles to, 120–123
  associated with decay, 140
  categorizing, 59–60, 62
  of codominant branches, 136–137
  defects and, 134–135
  defined, 45
  likelihood of impact and, 161–164
  of multiple branches originating at one point, 138
likelihood of impact, 10, 28–29
  categorizing, 53–55
  defined, 45
  likelihood of failure and, 161–164
limitations, 9–10, 191
limited visual assessment, (Level 1) report, 192
limited visual risk assessment, 23–27. *see also* tree risk assessments
  case study, 28–29
live crown ratio (LCR), 123, 152
load
  assessing, 127–129
  defined, 73, 117–118
  load-bearing capacity of trees, 73, 117, 118–120
  static, 117
  testing, 36, 37–38
  tree response to, 123–127

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M

mallet, 30
mass damping, 127
mathematical/computer modeling of loss in load-bearing capacity, 38–39
mechanical stress, 93–94
mechanics, defined, 117
missing wood, 139
mitigation options, 7, 175
mobile targets, 49
    occupancy rates of, 52
moments, 117
monocotyledonous trees, 93
movable target, 49, 52
mushrooms, 102

N

National Tree Safety Group (NTSG), 3
natural retrenchment, 182
negligence, 13
neutral plane of bending, 120
normal weather, 74
northern red oak *(Quercus rubra),* 92

O

occupancy
    occasional, 50–51
    rate, 49, 50–52, 161, 162
    rate, defined, 45
oozing, 154
    sap, 133
open-grown trees, 77
oral reports, 191, 192–193
overall tree risk rating, 167
overextended branches, 138

P

paper birch *(Betula papyrifera),* 92
parenchyma cells, 91, 92
pathogen, 102
Phaelous schweinitzii, 103
Phaeolus, 104
phloem, 91
Phytophthora infection, 154
pin oak *(Quercus palustris),* 33
Pinus, 107
Populus, 108
potential indicators of decay, 109, 112, 140
precipitation, 76
preclimb inspection, **16**
prioritizing targets, 65–67
probe, 30
proportionate, being, 6
props, 177
protection factors, 52
    defined, 45
pruning, 176–177

Q

qualitative numeric assessments, 10
qualitative risk assessments, 10
quantitative risk assessments, 9–10
Quercus, 108

R

rain tree *(Samanea saman),* 92
ram's horn, 95
rare occupancy, 51
rating risk, 164, 167
rays, 92
reaction wood, 91, 94
reaction zone, 102
reasonable, being, 6
reasonableness check, 168
reassessment interval, 191, 195
reconfiguration of crown, 117
remote sensing/imaging, 26
reporting, 29, 191

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limitations of tree risk assessment, 194
oral reports, 192–193
reassessment, 195
of tree assessment, 12
video or photographs, 193–194
written reports, 191–192
residual risk, 175, 183
resistance-recording drill, 35–36
response (adaptive) growth, 73, 84, 93–96, 99
defined, 93
properties, 95
restricted soil space, 155
retain and reassess, 183
retrenchment/natural crown reduction, 177
rhizomorphs, 108
ribs, 147–148
ridges, 142
ring porous, 92
risk. *see also* tree risk rating
associated with trees, 3–4
categorization process, 161
evaluation, 169
vs. hazard, 7
matrix (matrix 2), 161
perception and acceptable risk, 168–169
tolerance, 167
root
assessment, 36, 39–40
damage, 84
flare, 133
problems, 153–155
rots, 108–109
root collar excavation (RCX), 30–31, 40

S

safety, 184
saprophyte, 102
sapwood, 92, 103
decay, 123, 133, 141
rot (sap rot), 110
scope of work
defining, 10–12
in tree risk assessment, 23
seams, 133, 146–147
severe weather, 74
shallow soils, 81
shear, 120
plane cracks, 143, 145
site assessment, 83–85
history of failures, 82–83
site changes, 83
site factors, 73–74
site soil conditions, 79–82
topography, 78–79
tree exposure, 76–78
weather, 74–76
site changes, 74, 83
site evaluation, detailed, 34, 37
site modification, 179–180
slenderness, 123
slope, 78–79
aspect, 80
soft rots, 104
soil
compaction, 80
conditions, 74, 79–82, 84
depth, 80–81
disturbance, 82
drainage, 81
erosion, 155
grade change, 84–85
hydrology, 80, 85
moisture, 81, 155
mounding or cracking, 155
organic matter, 82
probe, **80**
quality, 81–82
testing, 82
texture, 82
volume, 80–81
sonic assessment, 36–37
sonic tomography, 36–37
sounding, 30

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standard of care, 13
static load, 117
static pull test, 37–38
static target, 48, 49, 52
stem girdling, 154
storm/wind load analysis, 36, 40
strain, 93–94
stratifying (systematic grouping) targets, 65–67
stress, 117, 119–120
  raisers, 121
structural support systems, 177–178
subdominant understory trees, 78
suberin, 106
subjectivity, 167–168
sudden branch drop (SBD), 139
summer branch drop, 139
sun exposure, 77, 84
suppressed trees, 78
sweep, 151

T

tape measure, 30
taper (slenderness), 123, 152–153
taproot, 81
target, 9
  aggregation, 56, 59–60, 62
  aggregation, defined, 45
  analysis, detailed, 34, 37
  categorization of, 48–49
  defined, 46
  known, 47
  stratifying and prioritizing, 65–67
  zone, 47–48
target assessment
  evaluating potential targets, 46–52
  occupancy rate and likelihood of impact, 58–59
  stratifying and prioritizing targets, 65–67
  tree risk assessment factors, 52–56, 59–60, 62–63, 65
target-based mitigation, 175–176
target protection factors, 53
target (risk target), defined, 45
target zone
  defined, 45
  occupancy, 50–52
tension, 117, 119
tension wood, 91, 94
time frame, 3, 50, 161
  defined, 45
  specifying, 53
  of tree assessment, 12
timetable for assessment and reporting, 12
tomograms, 36–37
topography, 78–79
torsion, 120
tracheids, 91
transverse cracks, 143, 144
TRAQ tree risk assessment approach, 10
tree architecture, 148–149, 151–152
tree-based mitigation, 175–176
tree biology
  CODIT, 105–108
  growth strategies, 93
  indicators of decay, 110–112
  location in the tree, 108–110
  progression of decay, 104–105
  response (adaptive) growth, 93–96, 99
  tree health and vigor, 99
  wood decay fungi, types of, 102–104
  wood structure, 91–93
tree conflict, 3, 6
tree dynamics tests, 38
tree exposure, 76–78
tree failures, 46–47
  defined, 4, 45
  history of, 82–83
  during normal weather conditions, 6
tree growth regulators (TGRs), 180–181
tree health
  evaluation, 41
  vs. structural stability, 94
tree inspection, 7
  comparison with tree risk assessment, *8*
tree mechanics

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applying mechanical principles to likelihood of failure, 120–123
assessing loads on trees, 127–129
load-bearing capacity of trees, 118–120
loads on trees, 117–118
tree response to loads, 123–127
tree removal, 179
tree ring analysis, 36
Tree Risk Assessment BMP methodology, *8*
tree risk assessments, 3, 28–29, 45–46
advanced assessment, 23, 24, 33–41
approaches to, 9–10
basic assessment, 23, 24, 30–32
case study, 9
comparison with tree inspection and worksite inspection, *8*
context of, 9–10
within the context of tree risk management, 5–7
defined, 7
evaluating potential targets, 46–52
factors, 52–67
limitations of, 9–10
limited visual, 23–29
process, 12–13
professional responsibilities, 13, 15
reporting limitations of, 186
safety, 15–16
scope of work, 10–12, 14–15, 23
tree risk assessors, 3, **4**, **5**, 6–7, 13, 14–15, 26, 27
advanced assessment, 33
basic assessment, 30
categorize occupancy, 52
categorizing consequences of failure, 63
categorizing likelihood of failure, 143
defects and likelihood of failure, 134–135
detailed site evaluation, 37
drilling, 35
estimating tree stability or loss in loadbearing capacity, 39
extent of internal decay assessment, 128
hand pull test, 37
heartwood rot assessment, 110
identification of hazards, 16
identification of targets, 47, 48
identification of wood decay fungi, 102
indicators of decay, 140
likelihood of failure assessment, 62
likelihood of failure rating assessment, 122–123
mitigation actions, 175–176
oral reports, 193
risk rating, 167
root failure assessment, **166**
significance of response growth assessment, 96
soil assessment, 82
soil conditions assessment, 84
tree architecture assessment, 148
tree load-bearing capacity assessment, 127
tree risk assessment, 194
understanding typical weather patterns, 74
use of soil probe, 79
variability among assessors' ratings, 167–169
wind exposure assessment, 83–84
tree risk evaluation, 3
tree risk management, 3, **4**
tree risk manager, 3, **5**, 6, 14–15, 28
establishing acceptable levels of risk, 168
information about occupancy, 52
mitigation actions, 182
oral reports, 193
target aggregation, 56
target consideration, 47
tree risk mitigation
installing lightning protection systems, 178–179
installing structural support systems, 176–178
modifying the site to enhance mitigation, 179–180
multiple mitigation actions, 182
prioritizing risk mitigation, 183
pruning, 176–177
residual risk, 183
retention for wildlife, 182
safety, 184
target-based, 175–176
tree-based, 176
tree removal, 179
using tree growth regulators, 180–181

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tree risk rating, 3, 15, 161
advanced assessment, 33
in basic assessment, 31
defined, 10, 11
overall, 167
steps in developing, 18–19, 169
tree species failure profiles, 155–156
tree structural failures, **11**
trenching/grade changes, 81
trunk
decay tests, 6
defects and conditions, 139–142
taper, 95

U

uncertainty, 167
unoccupied aerial vehicles (UAVs), 26

V

vascular cambium, 92
vessels, 91
veteran trees, 179
video or photographs, 193–194
visual assessment, 133, 134, 192

W

walk-by, 25–26
weather
analysis, 36, 41
categories, 73–74
and tree failures, 74–76
white ash *(Fraxinus americana),* 92, 128
white rots, 102, 93–104
wildlife habitat, 179, 182
wind
energy, 126
exposure, 83–84
funneling, 77
loads, 76–77, 176
speed, 74–75
velocity, 77
wind rose, **77**
chart, 36, 41
windthrow, 76
wood decay, 139
wood decay fungi
indicators of decay, 110–112
progression of decay, 104–105
types of, 102–104
work order, 191
worksite inspection, 7
comparison with tree risk assessment, *8*
wounded roots, 154
wounds
bleeding or oozing from, **112**
wound-induced discoloration, 110
woundwood, 91, 95, 106–107
written reports, 191–192

X

xylem, 91

Y

yew (*Taxus* sp.) tree, 145

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Matrix 1: Likelihood Matrix

The likelihood matrix used to categorize the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2: Risk Matrix

Risk matrix showing the level of risk as the combination of likelihood of a tree failing and impacting a specified target and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

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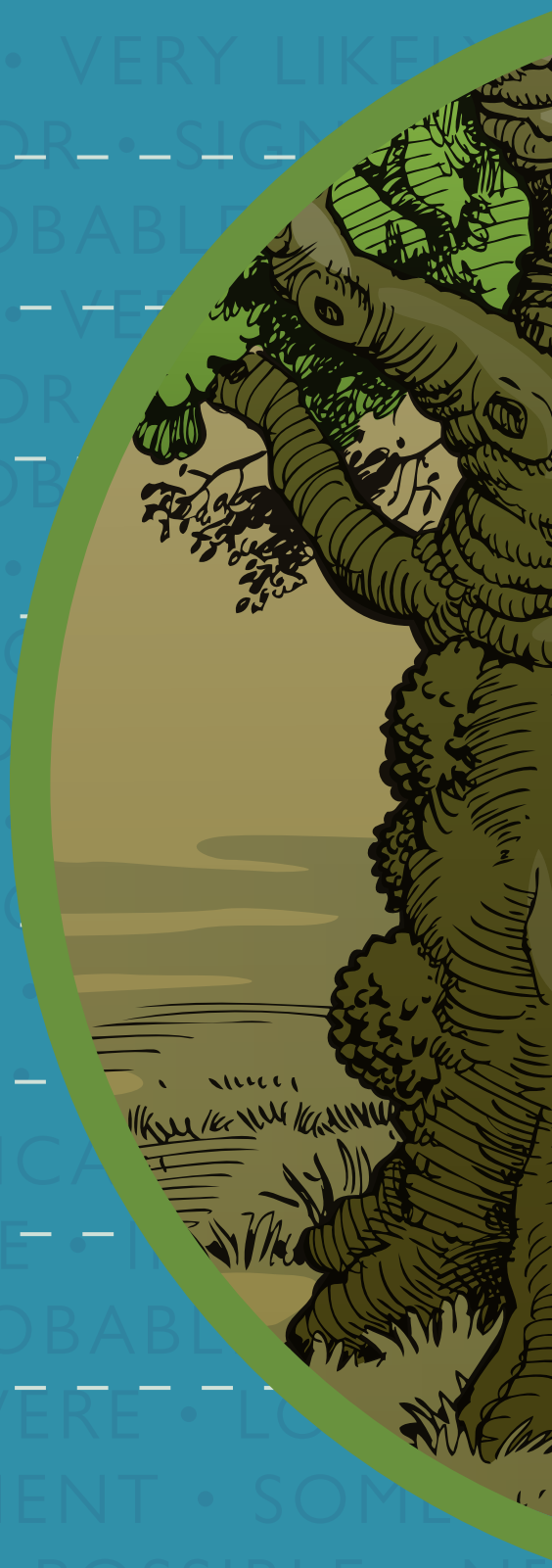

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